FIVE COUNTY SEISMIC SAFETY ELEMENT

FRESNO • KINGS • MADERA
MARIPOSA • TULARE COUNTYS

TECHNICAL REPORT I

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16. Abstracts

The distribution of seismic and related geologic hazards and their risk of occurrence are analyzed using the seismic record, variations in earth properties, computer assisted modeling techniques, and photogeologic studies. Results are displayed in map form, and expected earthquake shaking is defined as response spectra for each of the several microzones delineated within the study area. Conclusions as to the level and risk of the various hazards are included, and are also carried forward to the Policy Report, Part II, for recommended action.

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<u>*FIVE COUNTY SEISMIC SAFETY ELEMENT*</u>
for the
GENERAL PLANS
of
FRESNO, KINGS, MADERA, MARIPOSA
and
TULARE COUNTIES
and
THEIR RESPECTIVE INCORPORATED CITIES

APRIL, 1974

CONSULTANT
ENVICOM CORPORATION
SHERMAN OAKS, CALIFORNIA

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April, 1974

Robert E. Harrell, Chairman
Five County Seismic Safety Study Policy Committee
Tulare County Courthouse
Visalia, California 93277

Dear Mr. Harrell:

The Technical Committee of the Five County Seismic Safety Study has reviewed the work of the consultant, ENVICOM Corporation and their subcontractor, Quinton/Redgate. The Technical Committee, composed of representatives of the Council of Fresno County Governments, Kings County Regional Planning Agency, Madera County Planning Department, Mariposa County Planning Department, and the Tulare County Association of Governments has found the work completed to be satisfactory in that it (1) meets contractual obligations; (2) meets the requirements of the State of California for the Seismic Safety Element of the General Plan; and (3) meets all requirements of the Technical and Policy Committees.

Due to the rapid increase in knowledge regarding seismic conditions in California; changing requirements in planning law; and the need for continuity between planning elements as they are updated, we recommend that this report be considered as a benchmark in the continual upgrading of the Statewide effort towards provision of safety standards. These standards are absolutely necessary if we are to avoid the catastrophic effects of earthquakes, such as the ones that occurred at San Fernando in 1971, Long Beach in 1933, and San Francisco in 1906.

The members of the Technical Committee wish to express their appreciation to you for your leadership and constructive advice during the course of the study.

Cordially,

TULARE COUNTY ASSOCIATION OF GOVERNMENTS
Robert L. Wall, Executive Secretary

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I INTRODUCTION

A. SCOPE OF INVESTIGATION

Section 65302 (f) of the Government Code requires a Seismic Safety Element of all city and county general plans as follows:

> "A seismic safety element consisting of an identification and appraisal of seismic hazards such as susceptibility to surface ruptures from faulting, to ground shaking, to ground failures, or to the effects of seismically induced waves such as tsunamis and seiches.
>
> The seismic safety element shall also include an appraisal of mudslides, landslides, and slope stability as necessary geologic hazards that must be considered simultaneously with other hazards such as possible surface ruptures from faulting, ground shaking, ground failure and seismically induced waves."

The Guidelines (Council on Intergovernmental Relations, 1973) for the preparation of local general plans states that:

> "The intent is that all seismic hazards are to be considered, even though only ground and water effects are given as specific examples. The basic objective is to reduce loss of life, injuries, damage to property, and economic and social dislocations resulting from future earthquakes."

Based on the interpretation of the intent of the law, the Guidelines define the scope of the Element as including:

1. A general policy statement.

2. The identification, delineation and evaluation of natural seismic hazards.

3. The consideration of existing structural hazards.

4. An evaluation of disaster planning program.

5. The determination of specific land use standards related to level of hazard and risk.

The Guidelines recognize that "local planning agencies may wish to consider the preparation of the Element or portions of the Element in joint action" and that "this would be particularly practical for the study of natural seismic hazards." With this suggestion in mind, the Seismic Safety Element for the Five-County area has been prepared as two documents. Those parts of the overall study that are specifically related to, and therefore adoptable by, an individual county can be included in the Element for a county or city. On the other hand, the technical investigation of the natural seismic hazards (Item 2 above), which is most efficiently handled on a joint basis, is included as this separate volume covering the entire Five-County area.

The Guidelines indicate that the identification of natural seismic hazards should include the following:

"1. General structural geology and geologic history.

2. Location of all active or potentially active faults, with evaluation regarding past displacement and probability of future movement.

3. Evaluation of slope stability, soils subject to liquefaction and differential subsidence.

4. Assessment of potential for the occurrence and severity of damaging ground shaking and amplifying effects of unconsolidated materials.

5. Identification of areas subject to seiches and tsunamis.

6. Maps identifying location of the above charactistics."

The following technical evaluation is intended to meet or exceed these requirements.

The investigation was begun in July of 1973, and has consisted primarily of the review, compilation, analysis, and hazard-related evaluation of published and unpublished data relevant to the Five-County area. The velocity data used in the analysis of near-surface amplification was contributed by the Standard Oil Company of California, and much difficult-to-obtain material was made available by local representatives of County, State and Federal agencies. The slope-stability analysis is based on the study of stereoscopic pairs of aerial photographs provided by the county representatives of the Soil Conservation Service.

The primary emphasis in the study has been placed on an analysis of expected ground shaking because the seismic setting of the area indicates this is the principal hazard. The methodology employed is that normally reserved for the analysis of sites for high-rise structures, and it has been used herein to calibrate the necessarily more generalized zonation of the area. This analysis was made possible by the contribution of the velocity data by Standard Oil, and by the availability of the computer programs for multi-layer analysis developed by the Earthquake Engineering Research Institute at U.C.L.A.

The basic map scale used in the investigation and in the presentation of results herein is 1:250,000 (1" = 4 miles), and available data appropriate to such a scale has been utilized where available. The distribution of seismic/geologic hazards and microzones as shown is considered appropriate to the scale used, but local variations that may affect conditions at an individual site may be present.

B. PHILOSOPHY OF THE ANALYSIS

The quantitative study of the strong shaking of earthquakes is a relatively young science. It was begun in California in the early 1930's, but has been limited by the necessity of having the right instruments in the right place when a significant earthquake does occur. Much information has been acquired over the last 40 years, but there are significant gaps and much remains to be learned.

With this relatively limited level of basic data, two different approaches to the development of a Seismic Safety Element are available. One can utilize broad generalizations to describe expected events; certainly the inadequacies of the data favor this approach. On the other hand, if the results are to be used by engineers in designing safer structures, then a commitment to mathematical form is necessary. To this end, the analysis is developed in this way, whenever possible, and presented in chart or graph form. Qualitative descriptions of the results are included for the lay reader, and a brief discussion of methodology, terminology and concepts is included in Section D.

The basic philosophy within which this analysis has been developed is that the intent of the Seismic Safety Element is to plan and prepare for the future based on what we know today rather than waiting until we know all that we would like to know.

C. CONCEPTS, METHODOLOGY AND TERMINOLOGY

1. General Statement

The Seismic Safety Element is probably the most technically-oriented of all the mandated elements of the General Plan. For this reason, and because of the wider range of backgrounds and experience of expected readers, it is appropriate to include in the Introduction a discussion of concepts, methodology and terminology to be used in developing the technical base for this element. This discussion is intended to supply not only a dictionary function of technical terms and concepts, but, most important, to establish the systematic cause-and-effect relationships between the several seismic hazards, and the need for a systematic analysis of available information.

The topics discussed in the following sections of the Introduction are arranged in an order that becomes increasingly more difficult for the layman to understand. Sections 2 through 4 discuss concepts and terms commonly included in newspaper accounts of earthquakes, while later sections discuss the concepts necessary in the technical analysis of earthquake hazards. The latter are intended primarily for readers with engineering or scientific backgrounds, but may also be of interest to the lay reader.

The text of the report is arranged in a similar order. Each section becomes increasingly more complex, and the later sections are intended to document the analysis for engineers and earth scientists who may wish to expand on or apply the data to the detailed analysis of individual sites.

2. Types of Hazards

The several seismic hazards discussed in the C.I.R. Guidelines can be grouped as a cause-and-effect classification that is the basis for the order of their consideration. Earthquakes originate as the shock wave generated by movement along an active fault. The primary natural hazards are ground shaking and the potential for ground rupture along the surface trace of the fault. Secondary natural hazards result from the interaction of ground shaking with existing ground instabilities, and include liquefaction, settlement, and landslides and seiches (waves in lakes or reservoirs). In this context, tsunamis, or "tidal waves", and seiches (often considered secondary hazards) would be primary natural hazards.

The potentially damaging natural events (hazards) discussed above may interact with man-made structures. If the structure is unable to accommodate the natural event, failure will occur. The potential for such failure is termed a structural hazard, and includes not only the structures themselves, but also the potential for damage or injury that could occur as the result of movement of loose or inadequately restrained objects within, on, or adjacent to a structure.

3. Active Faults - The Source of Earthquakes

Earth scientists are generally agreed that earthquakes originate as the result of an abrupt break or movement of the rock in the relatively brittle crust of the earth. The earthquake is the effect of the shock waves generated by the break, much the same as sound waves (a noise) are generated by breaking a brittle stick. If the area of the break is small and limited to the deeper part of the crust,

the resulting earthquake will be small. However, if the break is large and extends to the surface, then the break can result in a major earthquake.

These breaks in the earth's crust are called faults. In California, faults are extremely common, and vary from the small breaks of an inch or less that can be seen in almost any road-cut, to the larger faults such as the San Andreas on which movement over many millions of years has amounted to hundreds of miles. In addition to the size of faults, their "age" is also important. Many large faults have not moved for millions of years; they are considered "dead" or no longer active. They were probably the source of great earthquakes millions of years ago, but are not considered dangerous today.

Since faults vary as to the likelihood of their being the source of an earthquake, considerable effort has, and is continuing to be expended by geologists and seismologists to determine and delineate the faults likely to generate significant earthquakes. The C.I.R. Guidelines define an active fault as one that "has moved in recent geologic time and which is likely to move again in the relatively near future. Definitions for planning purposes extend on the order of 10,000 years or more back and 100 years or more forward." Policies and criteria adopted by the State Mining and Geology Board on November 21, 1973, define an active fault, for purposes of the Alquist-Priolo Act, as one which has moved at the surface during Holocene time (last 11,000 years). The State Geologist, in response to the Alquist-Priolo Act, has approached the problem in terms of potentially active faults. These are defined as faults that exhibit evidence of movement at the surface during Quaternary time (last 3,000,000 years); except that any fault that has been shown by direct evidence to have not moved during Holocene time is considered inactive.

The approach used herein is essentially that of the State Geologist. That is, faults are considered as potentially active if they cut Quaternary rocks, and if it has not been shown that they do not cut Holocene rocks. In the review of available geologic maps and data for evidence bearing on this problem, some judgement has been used in evaluating the evidence. Geologic mapping is conducted at various scales and for many different purposes. Depending on the purpose and the interests of the geologists involved, mapping may or may not be useful as a source of evidence as to the state of activity of a fault. A local example is a fault mapped by Page and LeBlanc (1969) near the bedrock outcrops east of Fresno. While recent movement is suggested at one small locality, the fault is terminated near more extensive deposits that would establish the critical relationships if involved. Also, there is no discussion of the evidence for the fault in the text, and the cartographic detail leaves considerable to be desired. The study was conducted to evaluate groundwater conditions in the Fresno area. It is useful for the purpose for which it was intended, but it is of minimal value in evaluating recency of faulting.

A similar problem exists with respect to the scattered earthquake epicenters that exist in most parts of California. There is a general association of earthquake epicenters and active faults, but there also exists a general "background" that increases in number of events near the major faults. The scattered epicenters in the western Sierra Nevada and eastern San Joaquin Valley are a local example. They increase in number toward the Owens Valley fault zone, and their distribution (discussed further in text of report) suggests they are related to faulting in the Owens Valley rather than near any one of the individual epicenters.

One such event was the earthquake that occurred during the course of this study (Sept. 14, 1973) near the town of Reedley. The Richter magnitude was 4.2, but shaking was pronounced near the epicenter because of the unusually shallow focal depth (approx. 4 km). While this earthquake is considered a significant event by the residents of the area near the epicenter, it is not given greater consideration herein than any other earthquake of this magnitude that has occurred in the study area during the period of instrumental recording (about 40 years).

4. Describing an Earthquake

Several terms are used to describe the location, "size", and effects of an earthquake. A clear understanding of the meaning of these terms and their limitations is essential to an understanding of the results of the investigation.

The location of an earthquake is generally given as the epicenter of the earthquake. This is a point on the earth's surface vertically above the hypocenter or focus of the quake. The latter is the point from which the shock waves first emanate. However, as discussed above, earthquakes originate from faults. These are surfaces not points, so the hypocenter is only one point on the surface that is the source of the earthquake.

Magnitude describes the size of the earthquake itself. Technically it is defined as the log of the maximum amplitude as recorded on a standard seismograph at 100 kilometers (62 miles) from the epicenter. The most important part of this definition is that it is a log scale; that is, an increase of 1 on the magnitude scale (e.g. magnitude 5.0 to 6.0) represents an increase of 10 in the amplitude of the recorded wave. It should also be noted that the magnitude of an earthquake is determined at a considerable distance from the center of the earthquake, and that it is based on ground displacement.

Intensity describes the degree of shaking in terms of the damage at a particular location. The scale used today is the Modified Mercalli Scale, and is composed of 12 categories (I to XII) of damage as described in Table 1.

The Roman numerals are used to emphasize that the units in the scale are discrete categories rather than a continuous numerical sequence as is the magnitude scale. It is important to remember that intensity is a very general description of the effects of an earthquake, and depends not only on the size of the quake and the distance to its center, but also on the quality of the construction that has been damaged and the nature of local ground conditions.

5. Occurrence, Recurrence and Risk of Earthquakes

Earthquakes have had in the past a certain occurrence in space and time. These occurrences may or may not set certain patterns that can form the basis for predicting their occurrence in the future. When such occurrences are analyzed in time, certain characteristics may statistically recur at definite intervals. If it can be shown that a particular magnitude earthquake recurs on a fault on the average of once in a certain time interval, then that interval is said to be the recurrence interval for that magnitude. Or, if the interval of time is set (e.g. a 100-year period), then earthquakes of a particular magnitude will recur a certain number of times in the specified period. This number is then the recurrence rate for that magnitude.

In California, small earthquakes occur much more often than large earthquakes. Also, there is a fairly definite pattern in that the log (base 10) of the number of events of a particular magnitude that have occurred in the past is inversely proportional to the magnitude of those events. This relationship appears to apply to larger areas such as California and western Nevada, some smaller areas such as the Los Angeles Basin, and to some faults such as the Newport-Inglewood. However, this relationship does not apply to all faults, and it should be applied to small areas, such as cities or individual sites, with great care.

Recurrence intervals can be used to indicate the risk of earthquake in much the same way that recurrence is used to describe the risk of flooding (e.g. 100-year flood). There is one important difference, however. Flood is the result of a random combination of meteorlogical events, whereas current geologic theory indicates that the buildup of the strain released during an earthquake is more likely to be regular. This regularity suggests that prediction, to varying degrees, may be possible depending on the extent of understanding of a particular fault. In some cases this understanding is limited to a statistical regularity in the number and magnitude of earthquakes generated. For others, such as the San Andreas fault, much more is known on which to base an estimate of the risks involved. For others, little more is known other than that there is some degree of hazard involved.

6. Acceleration, Velocity and Displacement

The data of seismologists and geologists are, in general, not applicable to the engineering design of earthquake-resistant structures. The seismograph, for example, is a very sensitive instrument designed to record earthquakes at great distances. A level of shaking that would be meaningful to an engineer in designing a building would put most seismographs completely off-scale.

As a result, it has been necessary to design and install special instruments to record the strong motions of earthquakes that are of interest to the engineer in the design of earthquake-restraint structures. The first such instruments, principally accelerographs and seismoscopes, were installed by the U.S. Coast and Geodetic Survey in the late 1920's. Since that time, the instrumentation and analytical techniques have been continuously improved, and many excellent records have been obtained of the more recent strong earthquakes.

The following sections are a brief introduction to the concepts, data and application of strong-motion records. The science is relatively young, and is growing in bursts that follow the recording of a damaging earthquake.

The accelerograph is a short-period instrument (in contrast to the seismograph), and measures the acceleration of the ground or the structure on which it is mounted. Figure 1 shows the ground acceleration recorded just a few hundred feet from the causative fault during the 1966 earthquake centered near Parkfield in southeast Monterey County. The velocity and dis-

TABLE 1.
MODIFIED MERCALLI INTENSITY SCALE OF 1931
(from United States Earthquakes, U.S. Dept. of Commerce)

Intensity	Description of Damage
I	Not felt except by a very few under specially favorable circumstances. (I Rossi-Forel Scale)
II	Felt only by a few persons at rest, especially on upper floors of buildings. Delicately suspended objects may swing. (I to II Rossi-Forel Scale)
III	Felt quite noticeably indoors, especially on upper floors of buildings, but many people do not recognize it as an earthquake. Standing motorcars may rock slightly. Vibration like passing of truck. Duration estimated. (III Rossi-Forel Scale)
IV	During the day, felt indoors by many, outdoors by few. At night, some awakened. Dishes, windows, doors disturbed; walls make creaking sound. Sensation like heavy truck striking building. Standing motorcars rocked noticeably. (IV to V Rossi-Forel Scale)
V	Felt by nearly everyone, many awakened. Some dishes, windows, etc., broken; a few instances of cracked plaster; unstable objects overturned. Disturbances of trees, poles, and other tall objects sometimes noticed. Pendulum clocks may stop. (V to VI Rossi-Forel Scale)
VI	Felt by all, many frightened and run outdoors. Some heavy furniture moved; a few instances of fallen plaster or damaged chimneys. Damage slight. (VI to VII Rossi-Forel Scale)
VII	Everybody runs outdoors. Damage negligible in buildings of good design and construction; slight to moderate in well-built ordinary structures; considerably in poorly built or badly designed structures; some chimneys broken. Noticed by persons driving motorcars. (VIII Rossi-Forel Scale)
VIII	Damage slight in specially designed structures; considerable in ordinary, substantial buildings, with partial collapse; great in poorly built structures. Panel walls thrown out of frame structures. Fall of chimneys, factory stacks, columns, monuments, walls. Heavy furniture overturned. Sand and mud ejected in small amounts. Changes in well water. Persons driving motorcars disturbed. (VIII to IX Rossi-Forel Scale)
IX	Damage considerable in specially designed structures; well-designed, frame structures thrown out of plumb; great in substantial buildings, with partial collapse. Buildings shifted off foundations. Ground cracked conspicuously. Underground pipes broken. (IX Rossi-Forel Scale)
X	Some well-built wooden structures destroyed; most masonry and frame structures destroyed with their foundations; ground badly cracked. Rails bent. Landslides considerable from river banks and steep slopes. Shifted sand and mud. Water splashed (slopped) over banks. (X Rossi-Forel Scale)
XI	Few, if any, (masonry) structures remain standing. Bridges destroyed. Broad fissures in ground. Underground pipelines completely out of service. Earth slumps and land slips in soft ground. Rails bent greatly.
XII	Damage total. Waves seen on ground surfaces. Lines of sight and level distorted. Objects thrown upward into air.

placement curves have been derived from it by integration. It is a particularly good example of the relationships of these three parameters of motion because of the relatively "clean", single-displacement pulse that corresponds to two velocity peaks and four acceleration peaks. Figure 2 shows the more typically complex record of the San Fernando earthquake as recorded at Pacoima Dam.

Neither of the two, however, are typical records in terms of accelerations recorded. The Pacoima record shows the largest acceleration recorded to date (1.25g), and the Parkfield record (0.5g) was the largest recorded in the United States before the San Fernando earthquake.

It should be noted that accelerographs normally record three components; two in the horizontal plane at a right angle to each other, and one vertical. One component from the records of each of these two earthquakes is included as an example of this type of record.

Maximum acceleration is one of the basic parameters describing ground shaking, and has been the one most often requested by agencies such as FHA in determining the earthquake hazard to residential structures. It is particularly important for "low-rise" construction (one to five stories) and other structures having natural periods in the range of 0.3 - 0.5 seconds or less.

7. Frequency Content - Fourier and Response Spectra

The frequency content of the ground motion is particularly important for the intermediate and higher structures. The problem can be compared to pushing a child in a swing. If the pushes are timed to coincide with the natural period of the swing, then each push makes the swing go higher. However, if the timing is not right, then most of the push is lost "fighting" the natural period of the swing. The situation is similar during earthquakes. Structures have certain natural periods of vibration. If the pulses of the earthquake match the natural period of the structure, even a moderate earthquake can cause damaging movement. However, if the match is poor, the movement and resulting damage will probably be much less.

Two methods are commonly used to analyze and display the frequency content of an earthquake. A Fourier analysis is a common mathematical method of deriving the significant frequency characteristics of a time-signal such as the record of an earthquake. The results of the analysis are an amplitude term and a phase term. The amplitude is normally plotted against the period for that amplitude to give a Fourier amplitude spectrum for the range of frequencies that are of interest. Since the mathematical procedure is basically an integration of acceleration with time, the Fourier amplitude has the units of velocity.

A response spectrum is derived by a similar mathematical process, but is slightly different in concept. It represents the maximum response of a series of oscillators, having particular periods and damping, when subjected to the shaking of the earthquake. The result is also expressed in terms of velocity with the particular nomenclature depending on the precise method used to derive the spectrum.

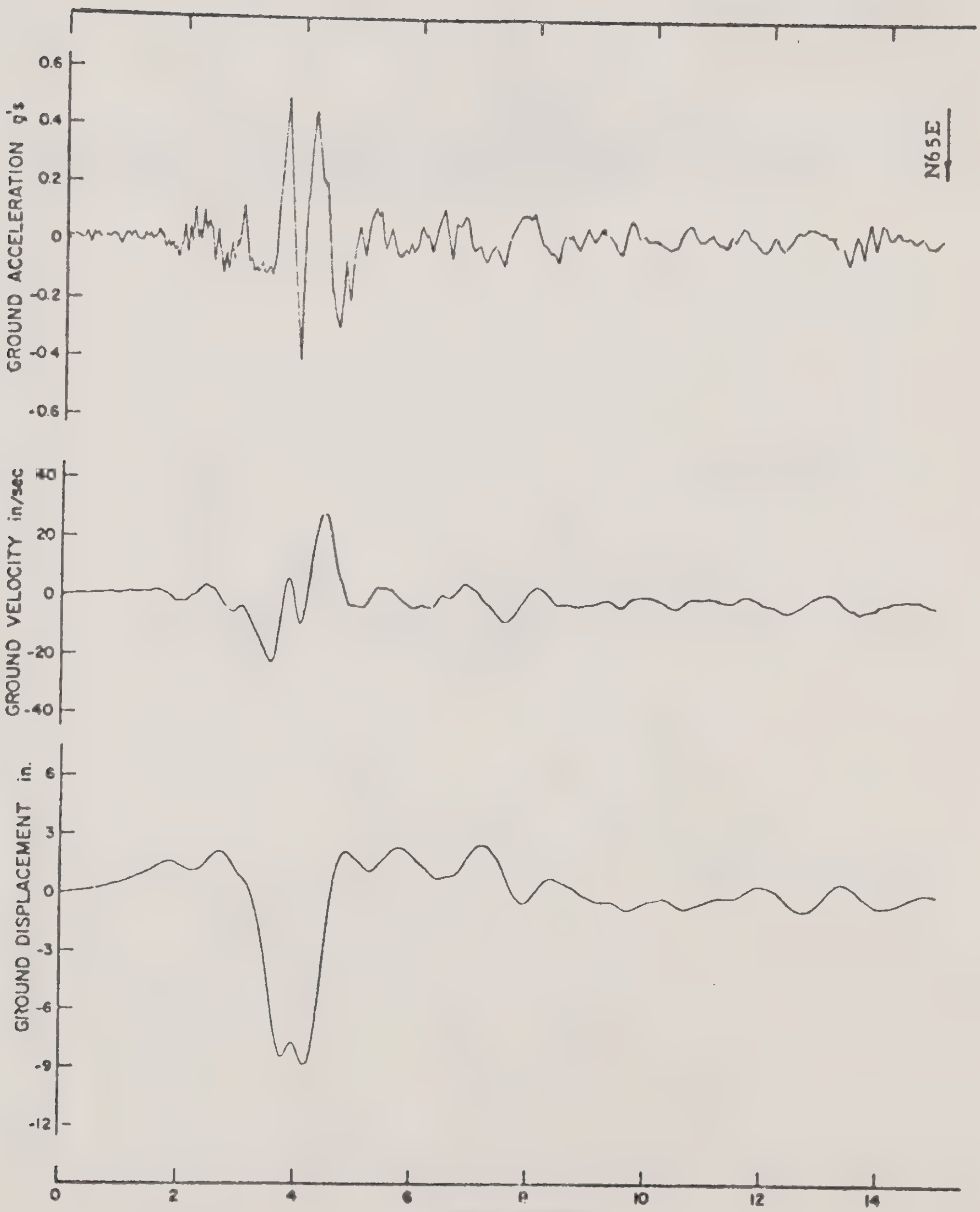
The Fourier spectrum can be generally described as a display of the energy available to shake structures having various natural frequencies. The response spectrum gives the effect, in maximum velocity, of this available energy on simple structures having various frequencies and damping. At zero damping the two are very similar. Figure 3 shows a plot of both the Fourier spectrum and the response spectrum with zero damping for the Taft, California record of the 1952 Kern County earthquake. Figure 4 shows the response spectrum for the Parkfield, California record (Figure 1) for several levels of damping.

8. Near-Surface Amplification

The shock waves of an earthquake radiate outward from the source (i.e. the slipped fault) through the deeper and relatively more dense parts of the earth's crust. In this medium, the waves travel at high velocity and with relatively low amplitude. However, as they approach the surface, the velocity of the medium decreases and may become quite variable if layers of different rock types are present. The overall effect is generally an amplification of the wave or of certain frequencies within the spectrum of the wave.

The most consistently applicable effect is the increase in wave amplitude that accompanies the decrease in velocity. This relationship can be compared to laws of mechanics that require the conservation of energy and momentum. In the case of earthquake waves, the energy of velocity is transferred to energy of wave amplitude when the velocity decreases.

A second effect is the amplification of certain frequencies due to the thickness and velocity of near-surface layers of the earth. The geometry of these layers controls the frequency of shaking just like the geometry of a TV antenna controls the frequency it receives best. A striking example is the very high amplification of



Station 2 N65E Motion.

FIGURE 1. Ground acceleration, velocity and displacement. 1966 Parkfield earthquake.

from Housner & Trifunac, 1967.

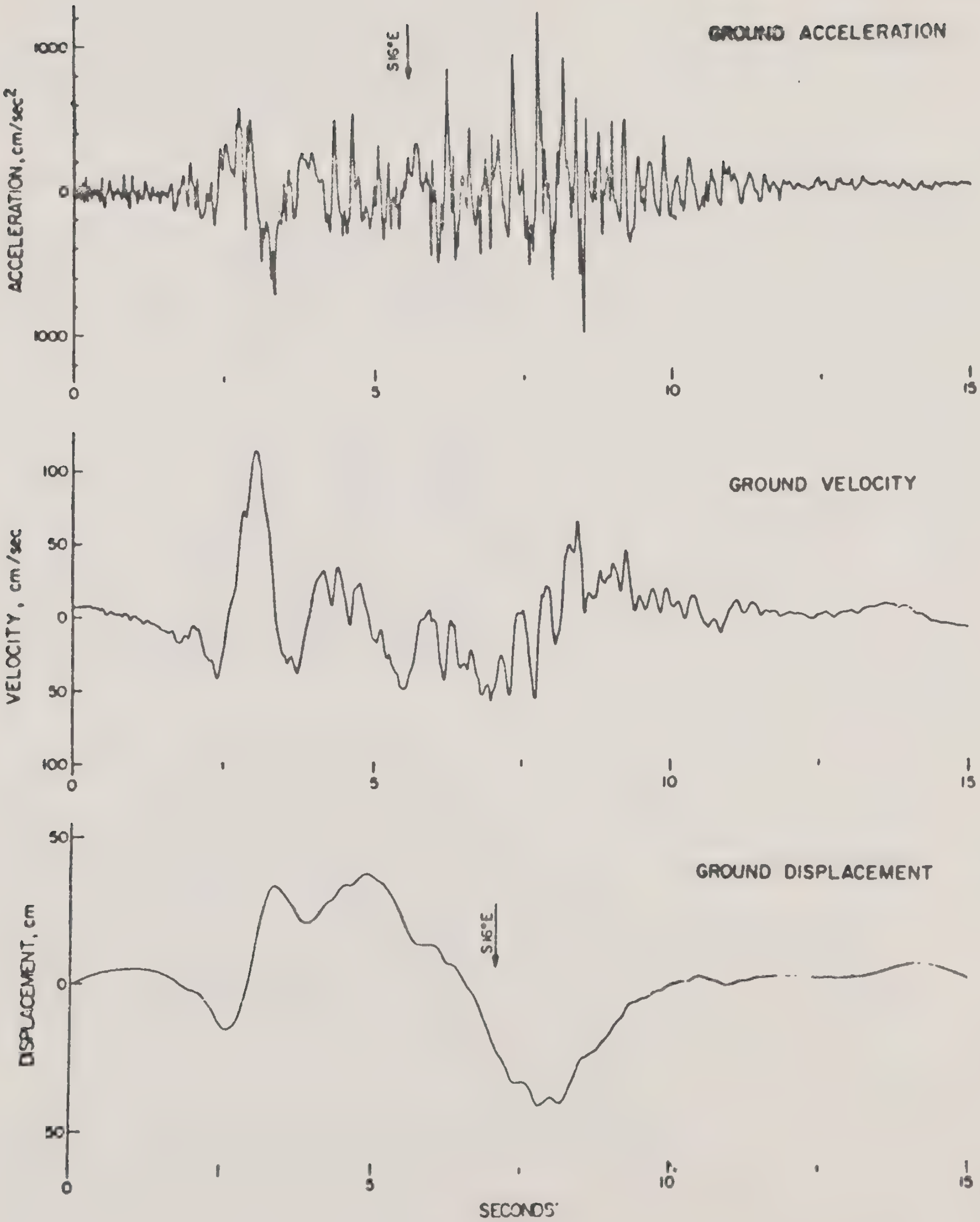


FIGURE 2. Acceleration, velocity and displacement in the S16° E direction during the main event of the San Fernando earthquake of February 9, 1971, 06:00 (PST).

from Trifunac & Hudson, 1971.

waves of 2.5-second period (Figure 5) by the stratification of the old lake beds on which Mexico City has been built. This concentration of the energy in a very narrow frequency range could be disastrous for structures with a matching natural period. Just like the child in the swing, they would move more and more with each successive pulse of the quake. Such pronounced amplifications are unusual, but if present, they can be extremely important.

D. ACKNOWLEDGEMENTS

We wish to express our sincerest appreciation to the management and personnel of the Standard Oil Company of California, Western Operations, Inc. for contributing the velocity data necessary in the analyses of near-surface amplification.

We also wish to express our appreciation to George Finney (Tulare County), Dave Knight (Fresno County), Dennis Triplitt (Kings County), Leonard Garoupa (Madera County), and the staffs of their respective planning departments for their efforts in furnishing ENVICOM with much of the necessary background material incorporated in this report. Bill Moffitt (Mariposa County Board of Supervisors) made several helpful suggestions regarding portions of the Technical Report.

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A special expression of appreciation is extended to King Leonard (Tulare County Planning Department) who acted as Chairman of the Five-County Seismic Safety Technical Committee. King's sincere concern with all aspects of the report provided needed direction while at the same time allowed us pursuit of our philosophy in preparing an understandable and useable document.

We are grateful to the United States Soil Conservation Service for providing us with excellent aerial photo coverage of the study area. Particular thanks are extended to the District Conservationists: Morris Martin (Fresno County), Bill Bruner (Tulare County), Ernie Eaton (Kings County), Bob Palmer (Madera County), and Don Lucas (Mariposa County), for their interest in the project.

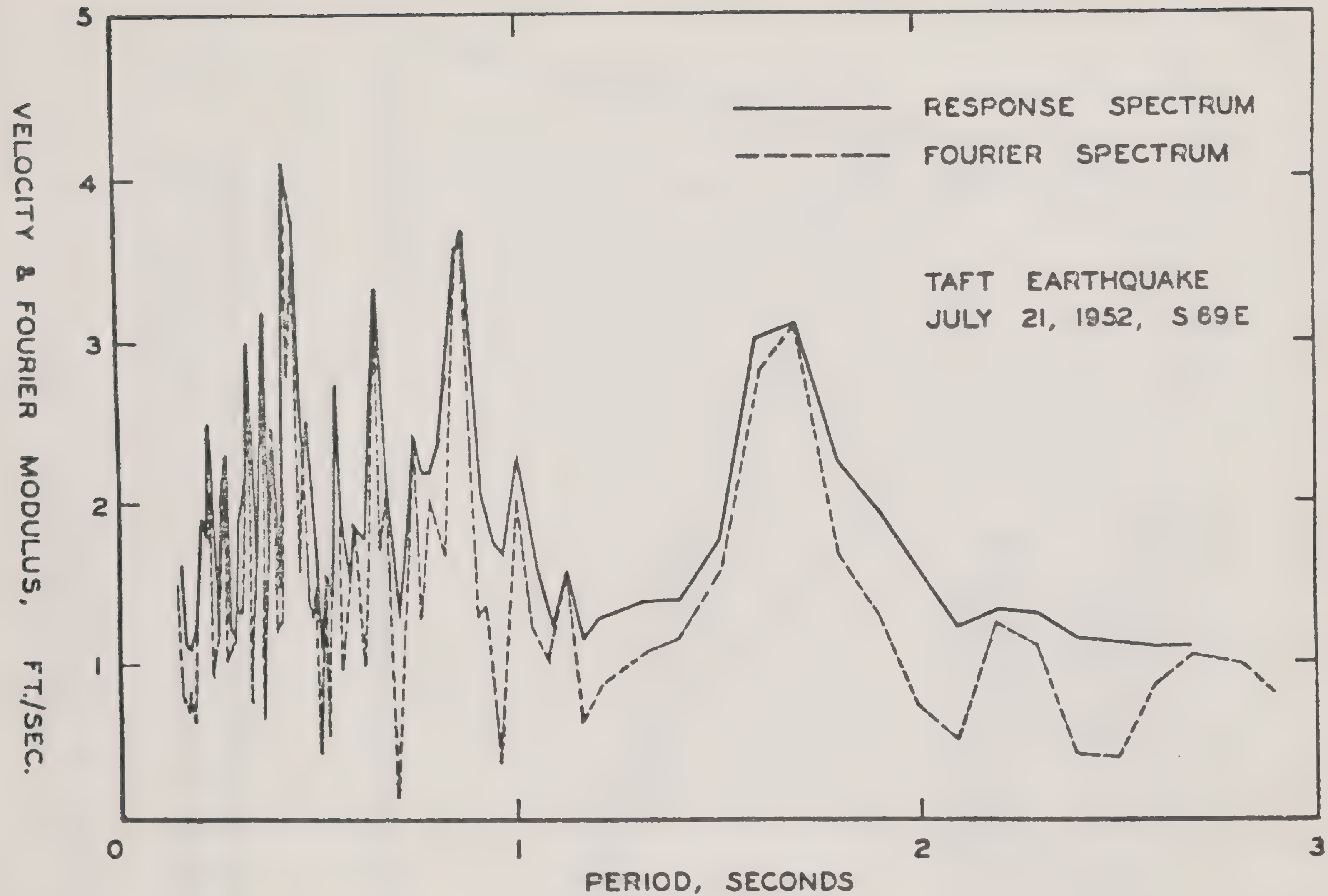


FIGURE 3. Fourier and response spectra, 1952 Kern County earthquake.

from Alford et al, 1964.

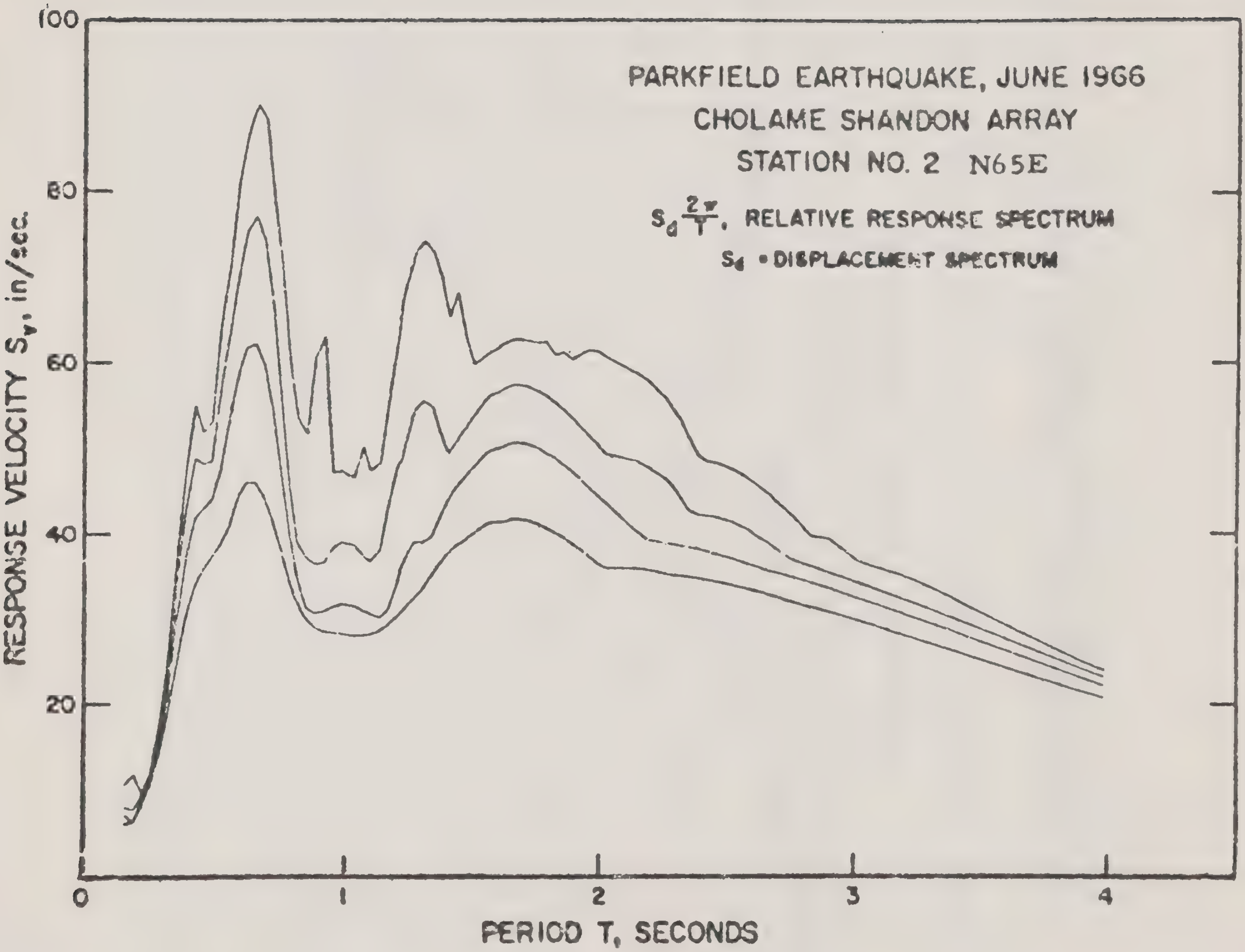


FIGURE 4. Response spectra, 1966 Parkfield earthquake. The curves are for 0, 2, 5 and 10% damping.

from Housner & Trifunac, 1967.

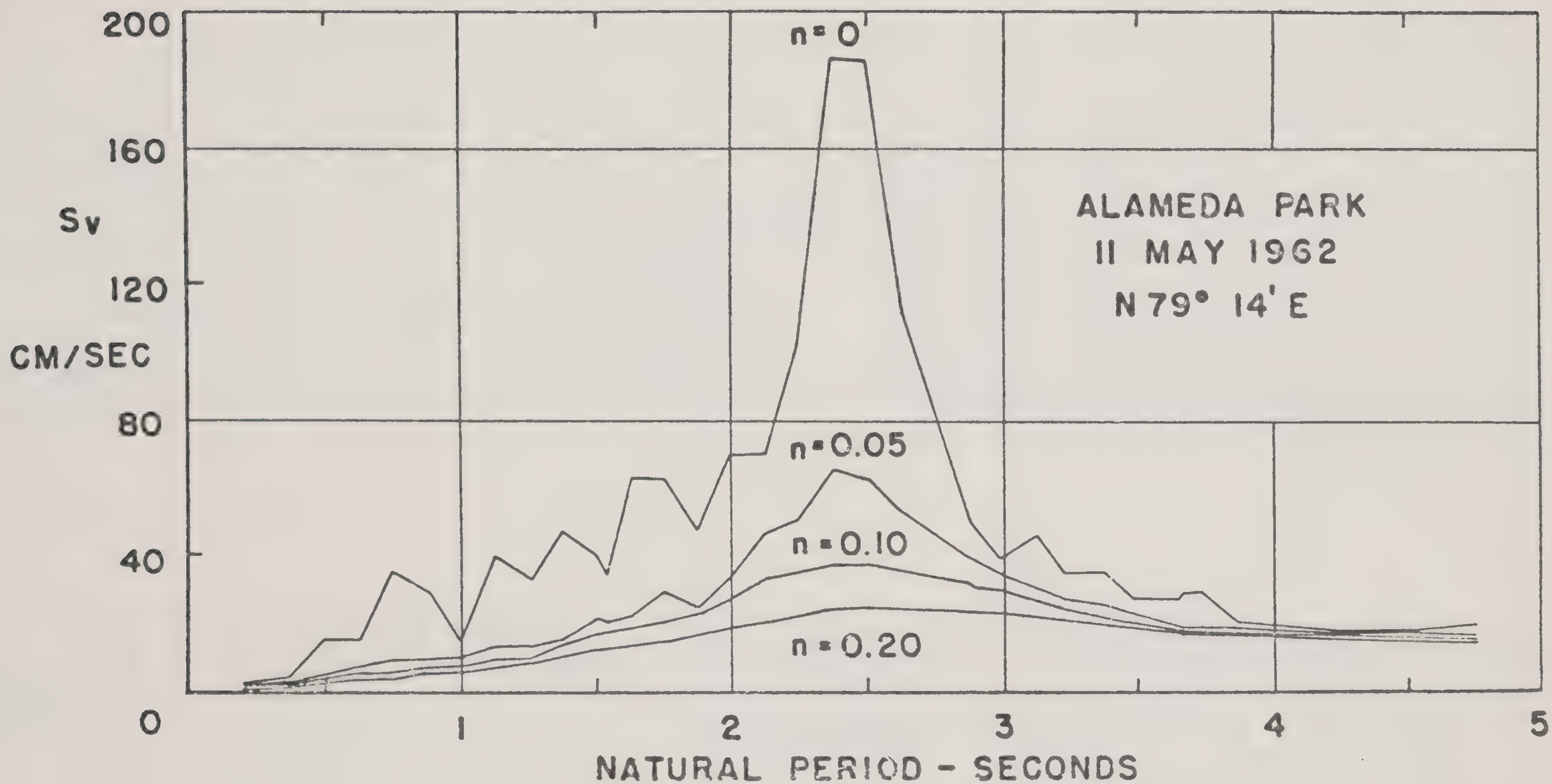


FIGURE 5. Velocity spectrum, 1962 earthquake near Mexico City.

(See "Mexican Earthquakes of 11 May and 19 May 1962," by P. C. Jennings, Earthquake Engineering Research Laboratory, C.I.T.)

A. GEOLOGIC AND SEISMIC SETTING

1. Major Physiographic and Geologic Provinces

The Five-County study area of Tulare, Kings, Fresno, Madera and Mariposa Counties includes three major physiographic and geologic provinces. The northeastern half of the area is included in the Sierra Nevada physiographic province and is underlain by igneous and metamorphic rocks. The central third of the area is included within the San Joaquin Valley, and is underlain by marine and non-marine sedimentary rocks to a depth of up to approximately 18,000 feet. The southwestern part of the area is included in the Coast Range physiographic province. Rocks in this area consist primarily of complexly folded and faulted older (Eocene and Cretaceous) sedimentary and Franciscan metamorphic rocks with younger sediments on the lower slopes of the hills and in some valleys.

The relationships of the three major provinces are shown on the geologic cross section (Figure 6). The rocks of the three major provinces significantly affect the level of earthquake shaking, and the boundaries of the provinces are shown on all maps involving shaking.

2. Major Structural Features

The major feature of the central and eastern part of the area is the tilted fault block of the Sierra Nevada. Since lower Cretaceous time, approximately 100 million years ago, the mountains have been rising and shedding sediment into the area of the Valley and parts of the mountains to the west. While the mountains were rising the area to the west was sinking, and sediments up to 18,000 feet or more in thickness accumulated in the seas that occupied the area.

The eastern boundary of this major tilted block is the fault system on the steep, eastern face of the Sierra Nevada. This fault system is active today, and will be discussed in greater detail as the Owens Valley fault group.

The mountains along the west side of the study area have had a long and complex history. A major complicating factor has been the San Andreas fault located just a few miles west of the western boundary of the Five-County area. While this fault has been well known since it was established as the source of the San Francisco earthquake of 1906, it has only been in the last 15 to 20 years that the mass of geologic knowledge has been sufficient to fully document the importance of this feature. It is now known that it is not only an important source of earthquakes, but that movement along this fault has amounted to hundreds of miles. These major features and their impact on seismic safety in the Five-County area are discussed in greater detail in the following sections of this report.

B. ACTIVE AND POTENTIALLY ACTIVE FAULTS

1. General Statement

Active faults that are known to be capable of generating earthquakes of magnitude 6 or greater, or those that are considered as potentially capable of generating earthquakes of this magnitude because of their length and geologic history, must be considered both as the location of surface rupture and/or the source of damaging earthquakes. This section of the report will discuss all known active or potentially active faults within the study area, and all major active faults sufficiently close to the study area to be the source of damaging earthquakes within the Five-County area. The purposes of this discussion are to delineate any faults within the area that should be considered as hazardous from the standpoint of surface rupture, and to establish those faults which will require further analysis of their capacity to generate damaging earthquake shaking.

2. San Andreas Fault

The San Andreas fault is probably the most important fault in determining the level of the hazard from ground shaking in the Five-County area. The long history of movements and earthquakes on this fault indicates that it is the most likely source of a damaging earthquake for most of the area. However, the San Andreas fault is not located within the Five-County area (Figure 7), so it is not a hazard with respect to ground rupture.

3. Owens Valley Fault Group

A complex group of faults located along or near the base of the steep, east slope of the Sierra Nevada (near fault 7 on Figure 7) is herein termed the Owens Valley fault group. All known active or potentially active faults within the group are east of the Five-County area, and do not present a hazard from ground rupture in the area. However, this fault group has been the source of numerous earthquakes in historic time, including the "great" earthquake of 1872, and it must be considered as second only to the San Andreas fault as a source of earthquakes that could cause damage in the area.

4. White Wolf Fault

The active White Wolf fault is also located outside the study area (fault 18 in Figure 7), and does not appear to be a hazard with respect to ground rupture in the Five-County area. This fault was little known until 1952 when movement along it generated the damaging series of earthquakes of that year in the Bakersfield area. The shaking from this series of shocks was the most severe in the Five-County area since the detailed compilation of intensity data was begun by the Coast and Geodetic Survey in 1928.

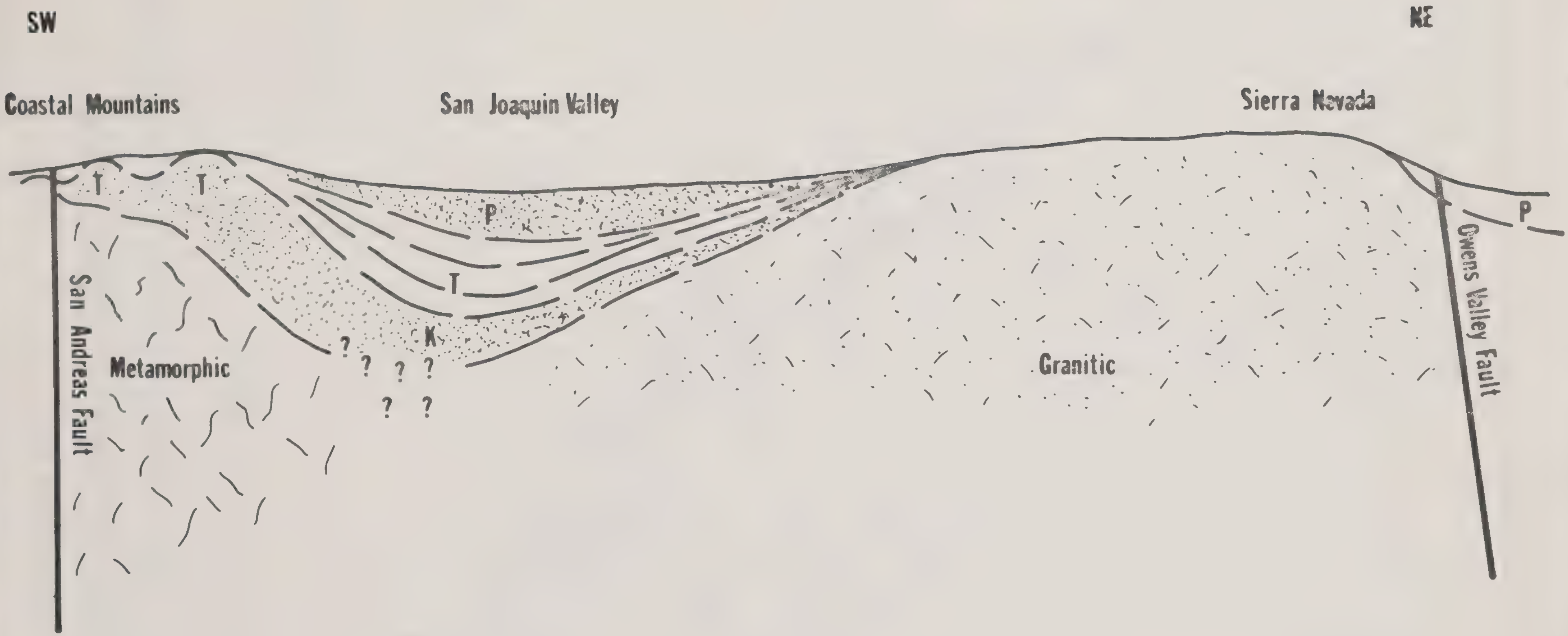


FIGURE 6 GENERALIZED GEOLOGIC CROSS SECTION. P = PLIO-PLEISTOCENE ROCKS; T = MIDDLE AND LOWER TERTIARY ROCKS; AND K = UPPER CRETACEOUS ROCKS.

GRAPHICS BY TULARE COUNTY PLANNING DEPARTMENT

SOURCE: ENVICOM

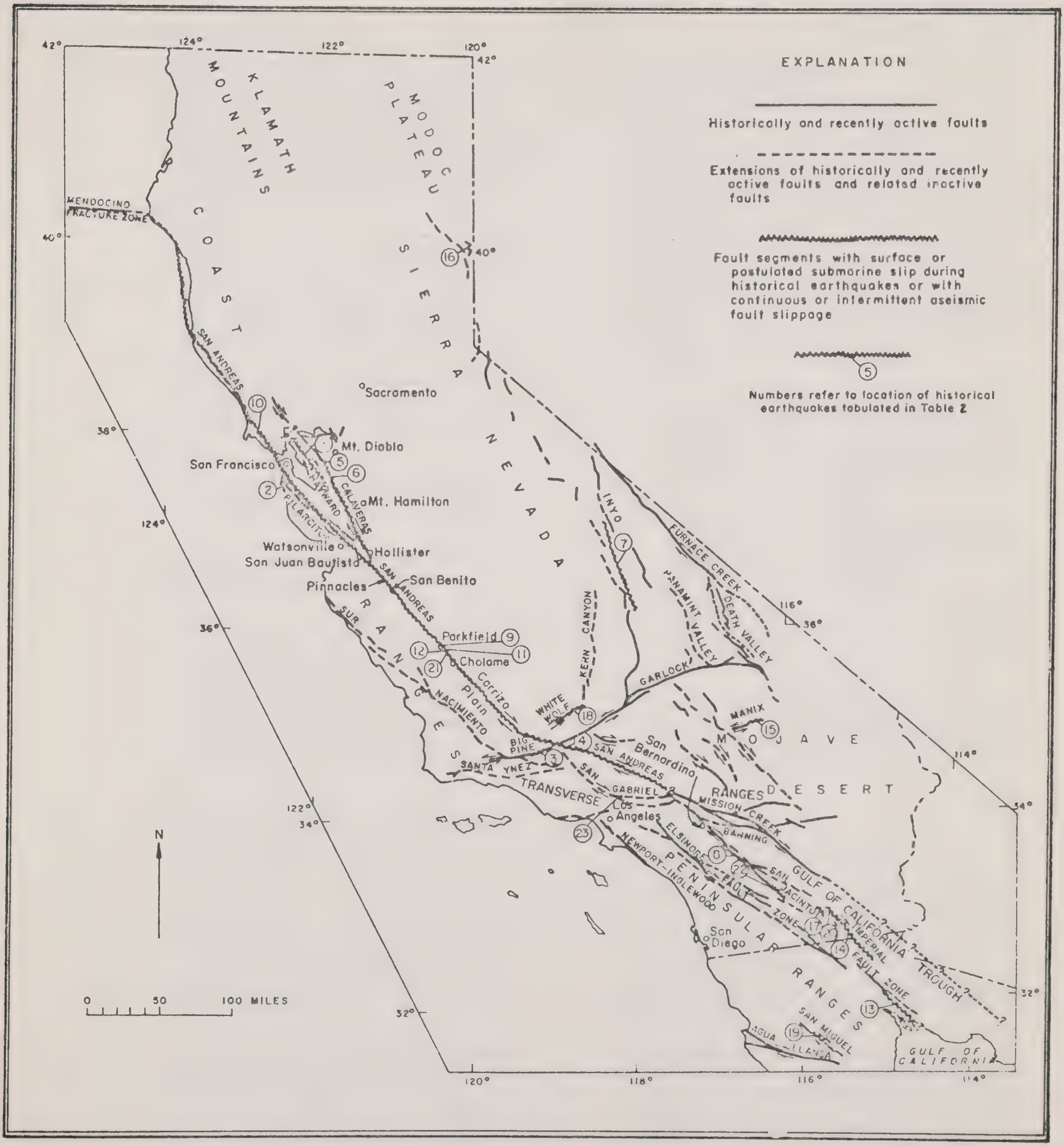


FIGURE 7 SURFACE FAULTING DURING HISTORIC EARTHQUAKES.

FROM GREENSFELDER, 1972.

5. Kern Canyon Fault

The Kern Canyon fault or fault zone is located in northern Kern County and eastern Tulare County (Figure 7). It trends northerly from near the northeast end of the White Wolf fault, through the Lake Isabella area, and generally along the Kern River. It must be considered suspect as a potentially active fault for the following reasons:

1. It is a major geologic feature of the southern Sierra Nevada mountains, extending for at least 80 miles as a continuous or semi-continuous fault or zone of faulting (Matthews and Burnett, 1965, & Smith, 1964).

2. Its location, extending northerly from near the northeast end of the White Wolf fault, suggests that it could be a continuation of this active fault.

3. There is a local increase in the concentration of earthquake epicenter activity (Plate I) near the fault.

However, the Kern Canyon fault is herein considered inactive for the following reasons:

1. The fault is overlain by a lava flow in Township 20 South, Range 33 East that is apparently not offset by the fault (Matthews and Burnett, 1965). The age of this flow of 3.5 million years ± 0.1 million years (Dalrymple, 1963) dates the last movement of this fault as at least 3.4 million years ago.

2. The concentration of earthquake epicenters noted above is located closest to that segment of the fault on which the last movement is dated by the lava flow.

3. Mapping by Webb (1946) indicates that the Kern Canyon fault is not one fault but a series of unconnected smaller faults. He (Webb, 1955) explains this as one consequence of the great age of the fault.

4. The interpretation of the Kern Canyon fault as an extension of the White Wolf fault would not fit current theory which regards the White Wolf fault as being one of several faults that relieve strain that accumulates near a major bend in the San Andreas fault.

6. Kern Front Fault Group

A group of small faults, located primarily in northern Kern County, is shown on the State Geologic Map as cutting the Plio-Pleistocene Kern River Formation. Two of the faults extend into Tulare County in Township 24 South, Range 27 East. The faults are dashed, indicating that they are only approximately located, and they are shown with question marks, indicating that their presence is questionable. While they should be considered as potentially active, the likelihood of either ground rupture or damaging earthquake on these faults is considered very low for the following reasons:

1. They are relatively short features, and do not have the length that would be expected of a strike-slip fault capable of generating a damaging earthquake or of causing surface rupture.

2. Their topographic expression is poor and they do not separate nor are they associated with major topographic features as would be expected of a major reverse or normal fault.

3. Earthquake epicenters are almost completely lacking in the area of these faults (Plate I).

4. They cut the older Plio-Pleistocene Kern River Formation, but do not cut the younger Pleistocene continental units (older alluvium) or river terrace deposits (Hilton, et al, 1963).

C. EARTHQUAKE SHAKING

1. Sources of Expected Earthquakes

The primary sources of earthquake shaking in the Five-County area are the San Andreas fault, the Owens Valley fault group, and the White Wolf fault. The Kern Canyon fault or "lineament" and the Kern Front fault group are not considered significant sources of earthquake shaking that would exceed that from the three major sources.

These three sources are considered in the following sections from the standpoint of their geologic and seismic histories and the characteristics of past and expected future earthquakes that can be expected to originate from them. The overall objective of this analysis is to establish the risk of movement and the engineering characteristics of certain "design earthquakes" as they will affect the various parts of the Five-County area.

TABLE 2
TABULATED LIST OF HISTORICAL EARTHQUAKES SHOWN IN FIGURE 7

	Date and Fault	Earthquake Magnitude	Movement
1.	1836 - Hayward fault	7.0 ± 0.5 (est.)	Ground breakage
2.	1838 - San Andreas fault	7.0 ± 0.5 (est.)	Ground breakage
3.	1852 - Big Pine fault	no data	Ground breakage
4.	1857 - San Andreas fault	8.0 ± 0.5 (est.)	Right-lateral, possible as much as 30'
5.	1861 - Calaveras fault	no data	Ground breakage
6.	1868 - Hayward fault	7.0 ± 0.5 (est.)	Strike slip
7.	1872 - Owens Valley fault zone	8.3 ±	Down to E. 23'; right-lateral, 16' - 20', but some reports state left-lateral movement also occurred
8.	1899 - San Jacinto fault	6.6 ± 0.42	Surface evidence questionable
9.	1901 - San Andreas fault	6.3 ± 0.42	Ground breakage
10.	1906 - San Andreas fault	8.3	Right-lateral, 21'
11.	1922 - San Andreas fault	6.5	Ground breakage
12.	1934 - San Andreas fault	6.0	Ground breakage
13.	1934 - San Jacinto fault zone in Colorado River Delta	7.1	Distinct fault trace on 1935 aerial photographs
14.	1940 - Imperial fault	7.1	Right-lateral, 19'
15.	1947 - Manix fault	6.4	Left-lateral, 3"
16.	1950 - Unnamed fault along west edge of Fort Sage Mountains	5.6	Down to W. 5" - 8"
17.	1951 - Superstition Hills fault	5.6	Right-lateral, slight
18.	1952 - White Wolf fault	7.7	Reverse fault, south plate moved from SW to NE; left-lateral, 2'; throw 2'
19.	1956 - San Miguel fault	6.8	Right-lateral, 3'; down to SW 3'
20.	1966 - Imperial fault	3.6	Right-lateral, 1-1/2 cm
21.	1966 - San Andreas fault	5.5	Right-lateral, several inches
22.	1968 - Coyote Creek fault (San Jacinto fault zone)	6.5	Right-lateral, 33 cm.
23.	1971 - San Fernando fault	6.6	Left-lateral, 6'; reverse, 6'

From Greensfelder, 1972.

2. Recurrence of Earthquakes

a. Objective of Analysis

The basic objective of the analysis of the recurrence of earthquakes is to establish, as closely as possible with the information available, the approximate time span between earthquakes of various magnitudes originating on a particular fault. These time spans are called recurrence intervals, and they generally relate to the risk, or probability, of an earthquake occurring in a given period of time. For faults such as the San Andreas that have been intensively studied, the information can also be combined to indicate the approximate time of the next big earthquake. While such an interpretation is tempting, it should be avoided. The seismic record is simply not long enough to justify estimates of this type.

The recurrence of earthquakes of various magnitudes can be derived in at least three different ways:

1. The analysis of the seismicity of a fault may reveal relationships that indicate that, at least statistically, earthquakes of particular magnitudes recur at regular rates. Data suitable for this type of analysis is available for only about the last 40 years.

2. The measurement of the movement of the earth on either side of a fault, or crustal strain, can sometimes be derived from survey data. This information is available for a longer period of time, but movement is often so small it is not detectable from ordinary data. Very accurate surveys have been conducted in recent years, but across only a few faults. If the rate of accumulation of strain is known, then the amount of time necessary to accumulate the strain necessary for an earthquake of a particular magnitude can be estimated from other relationships.

3. The relationship of unique rock units on either side of a fault may yield the geologic slip rate if the ages of the unique units are known. The principal problem with this method is the assumption that rates obtained for a time span of several million, or several tens of millions, of years are valid today.

The applicability of any of the above methods depends on the data available. Of the faults pertinent to this investigation, the San Andreas is the best known, and data is available with which to utilize all three methods. Therefore, the San Andreas is considered first, as the results of this analysis will aid in evaluating the lesser known faults.

b. San Andreas Fault

1. Seismicity

As discussed earlier, the San Andreas fault varies as to its state of activity along its length from the Gulf of California to Cape Mendocino (Figure 8). The areas of differing activity bearing on this investigation are the 1857 Break and the Central California active area. The former is essentially "quiet" (i.e. devoid of significant earthquake activity), while the latter is the site of large numbers of earthquakes.

Records of earthquakes in the active area are of two different types. The University of California Seismographic Station at Berkeley has been recording the location and magnitude of earthquakes in this area since 1932. More recently, the U.S. Geological Survey in cooperation with other interested agencies set up a network of closely spaced seismographic stations between Cholame in San Luis Obispo County and the Bay Area. Since this data is more detailed, it is analyzed separately from that recorded by the regional stations. This more detailed data is referred to herein as "microseismic" data, while the regionally recorded data is referred to as "macroseismic" data.

Microseismic data for the San Andreas fault system in central California have been compiled for the period of 1969 through the first half of 1972 by Lee et al (1972A), Lee et al (1972B), Lee et al (1972C), Wesson et al (1972A), and Wesson et al (1972B). From this data, the number of earthquakes for each year that occurred between Cholame and Paicines (Latitude 35° 45' to 36° 40' N) are compiled by half magnitude intervals, and summarized in Table 3 as the number of events in that time interval and also as the number of events in an arbitrarily chosen, standard interval of 100 years. The data used were limited to the area south of Paicines because the fault system becomes very complex to the north. A map showing a typical distribution of microseismic events and the complexity of the pattern north of Latitude 36° 40' N is included as Figure 9.

TABLE 3
MICROSEISMICITY OF SAN ANDREAS FAULT
CHOLAME TO PAICINES (35° 45' to 36° 40' N. Lat.)

	Number of Events in Time Interval					Number of Events Per 100 Years				
Magnitude	1969	1970	1971	1st half 1972	1969 to 1st half 1972	1969	1970	1971	1st half 1972	1969 to 1st half 1972
0.0 - 0.4	7	18	-	57	82	700	1,800	-	11,400	2,343
0.5 - 0.9	17	53	92	489	651	1,700	5,300	9,200	97,800	18,599
1.0 - 1.4	40	188	299	672	1,199	4,000	18,800	29,900	134,400	34,255
1.5 - 1.9	97	229	295	410	1,031	9,700	22,900	29,500	82,000	29,456
2.0 - 2.4	77	103	131	225	536	7,700	10,300	13,100	45,000	15,314
2.5 - 2.9	29	41	38	48	156	2,900	4,100	3,800	9,600	4,457
3.0 - 3.4	8	12	21	23	64	800	1,200	2,100	4,600	1,828
3.5 - 3.9	2	5	4	8	19	200	500	400	1,600	543
4.0 - 4.4	2	1	0	0	3	200	100	0	0	86
4.5 - 4.9	0	0	0	1	1	-	-	-	200	29
5.0 - 5.4	0	0	0	1	1	-	-	-	200	29

from: Catalogues of earthquakes along the San Andreas fault system in Central California for the years: 1969, 1970, 1971, Jan - Mar 1972, Apr - June 1972; U.S.G.S. Open File Reports, 1972.

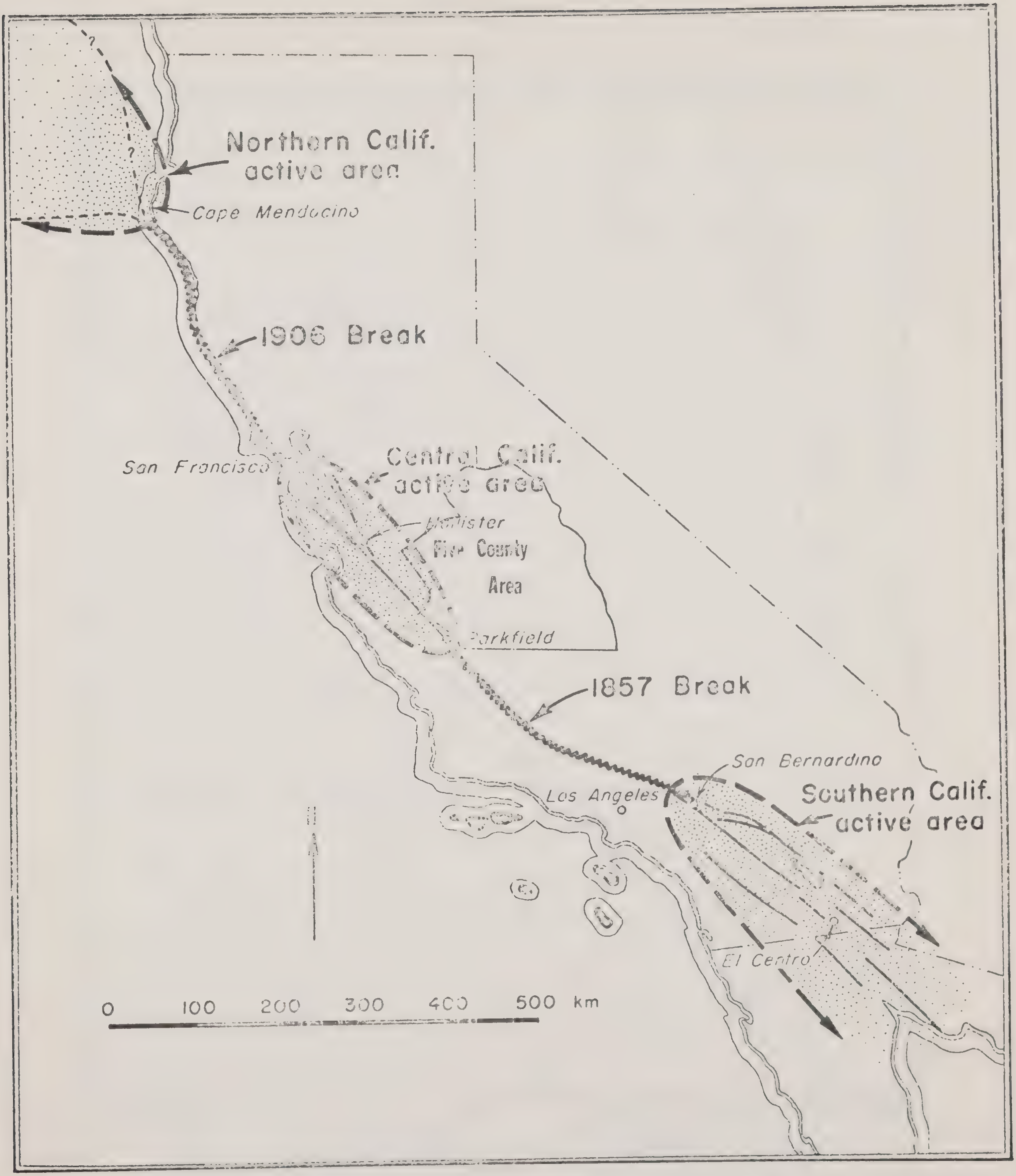
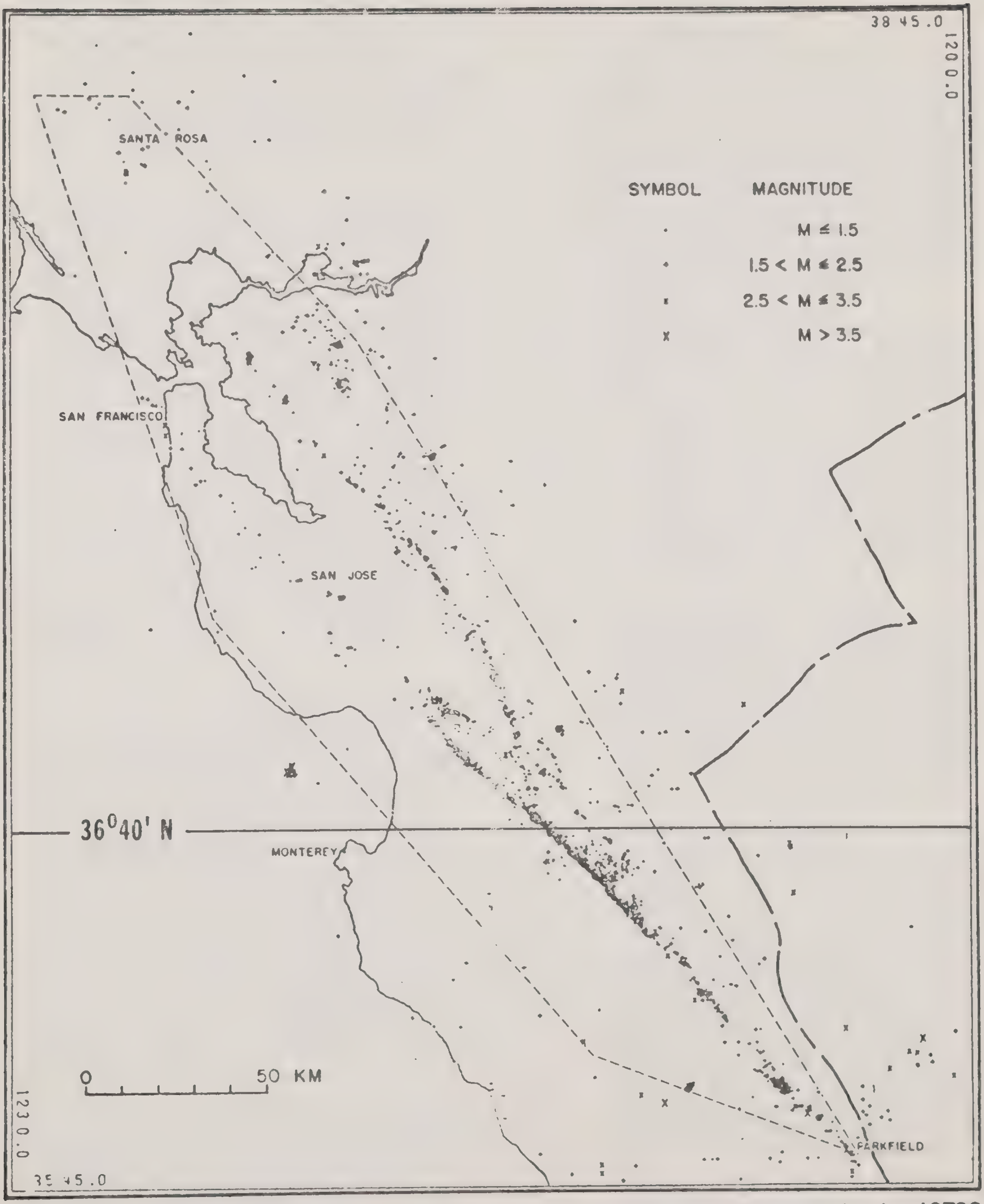


FIGURE 8 TYPES OF SEISMIC AND EARTHQUAKE ACTIVITY ON THE SAN ANDREAS FAULT.

FROM ALLEN, 1968



Source: From Lee et al, 1972C

FIGURE 9 SEISMIC EPICENTERS FOR 1971, SAN ANDREAS FAULT SYSTEM IN CENTRAL CALIFORNIA, SHOWING LINEAR PATTERN OF DISTRIBUTION IN AREA SOUTH OF 36° 40' N.

The data in Table 3 for the normalized 100-year interval are plotted on the graph, Figure 10, for each complete year and for the total 3.5 year interval. The method used is similar to that of Allen et al (1965) except that the number of events has not been normalized for a standard area. Therefore, the graph shows recurrence rates (events per 100 years) for various earthquake magnitudes for the 87-mile length of the San Andreas from which the data was recorded.

This method of deriving and displaying recurrence rates will be utilized frequently in the next few pages of this report, and additional comment is appropriate at this point. Simply stated, recurrence plots such as Figure 10 show that there are many more small earthquakes than large ones. More important, however, the plot demonstrates a consistent mathematical relationship between the occurrence of earthquakes of various magnitudes. This relationship suggests that our relatively short record of earthquake activity (about 40 years) can be used to evaluate the recurrence of larger earthquakes that have not yet occurred because of the relatively short time involved. This evaluation should be made with great care and considerable geologic judgement. Where the data are available, the results will be compared with the results of other methods as a check on the consistency of the analysis.

The data shown on Figure 10 are typical of plots of this type in that the plotted points for the larger magnitude events show a considerable "scatter." This should be expected as these points represent a very few events. Also, the number of smaller-magnitude events does not fit the "straight-line" relationship that appears valid for the intermediate magnitudes. Instead they "fall-off" rapidly below a magnitude of about 2.0 simply because the number of seismograph stations is not adequate to record all the smaller events. This relationship can also be seen in the variation of the curves with time. 1969 was the first year this microseismic recording network was in operation, and its ability to record the smaller events has increased each year.

The larger magnitude earthquakes, generally magnitude 3.0 or greater, have been recorded for a much longer period of time. Data recorded by various public and private agencies and stored in the digital file of the Berkeley Seismographic Station of the University of California are shown on Plate 1, and are tabulated for the Cholame to Paicines segment of the San Andreas fault in Table 4. The time interval for which magnitudes are available is 1932 through 1971, a period of 40 years. Display of the data is similar to that used for the microseismic data; recurrence rates are normalized to an interval of 100 years and plotted on Figure 11.

The recurrence rates from the macroseismic and the microseismic data will be compared as a part of the discussion of the results of various methods.

2. Crustal Strain

An alternative method of evaluating recurrence rates of a fault is based on the measurement of accumulating strain on either side of the fault, actual movement or slip that may be taking place, or combinations thereof. If the overall rate of movement can be established, recurrence rates can be computed from empirical relationships between the amount of fault movement during an earthquake and the magnitude of the earthquake.

Current and historic movement along the San Andreas fault from Paicines southward to the vicinity of Camp Dix is summarized by Brown and Wallace (1968) as follows:

"1. From Paicines to Parkfield -- relatively continuous fault creep of about 0.8 inch per year accompanied by very frequent but small earthquakes. Slip is probably chiefly tectonic creep, but a fraction of an inch of sudden slip may accompany some earthquakes.

2. From Parkfield to Cholame -- southward-decreasing rate of slip; slip is chiefly spasmodic and accompanies earthquakes of moderate magnitude. Earthquakes are commonly at shallow focal depths and are accompanied by surface fault breaks. Earthquakes and associated fault movements are apparently cyclical, recur every 10-15 years, and exhibit sudden slips of from 2-10 inches.

3. From Cholame to Camp Dix -- no evidence of either current slip or appreciable earthquake activity. However, this segment was the site of a great earthquake in historic time, and geomorphic evidence suggests repeated prehistoric displacements, presumably associated with equally great earthquakes. One hundred and ten years have now elapsed since the great earthquake of 1857, which suggests that the interval between events in this segment is many times that in the segment between Parkfield and Cholame. Sudden slip accompanying the 1857 earthquake may have been as much as 30 feet."

When taken in the context of the several areas along the fault having different types of activity (Figure 8), the segment south of Cholame is a part of the "1857 Break," and the segment north of Parkfield is part of the Central California active area. The segment between, from Cholame to Parkfield can be considered a transition zone with characteristics intermediate between the segments to the north and south.

TABLE 4
MACROSEISMICITY OF SAN ANDREAS FAULT
CHOLAME TO PAICINES (35° 45' to 36° 40' N. Lat.)
1932 through 1971

	Number of Events	
Magnitude	1932-1971	Per 100-years
2.0-2.4	35	87.5
2.5-2.9	82	205.0
3.0-3.4	460	1150.0
3.5-3.9	181	452.5
4.0-4.4	80	200.0
4.5-4.9	30	75.0
5.0-5.4	13	32.5
5.5-5.9	4	10.0
6.0-6.4	1	2.5

from: University of California, Berkeley Seismographic Station digital data file, searched July 30, 1973.

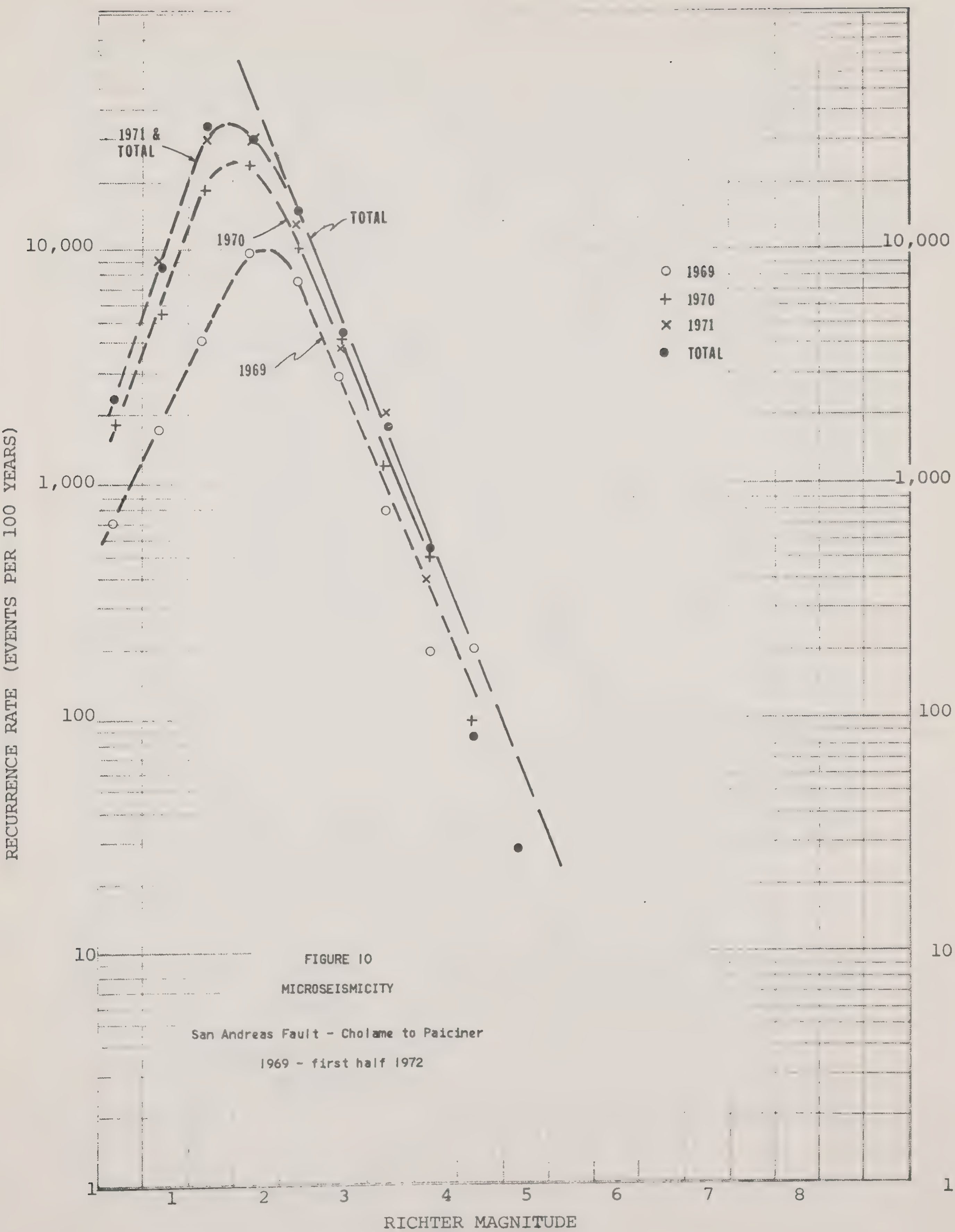


FIGURE 10

MICROSEISMICITY

San Andreas Fault - Cholame to Paiciner

1969 - first half 1972

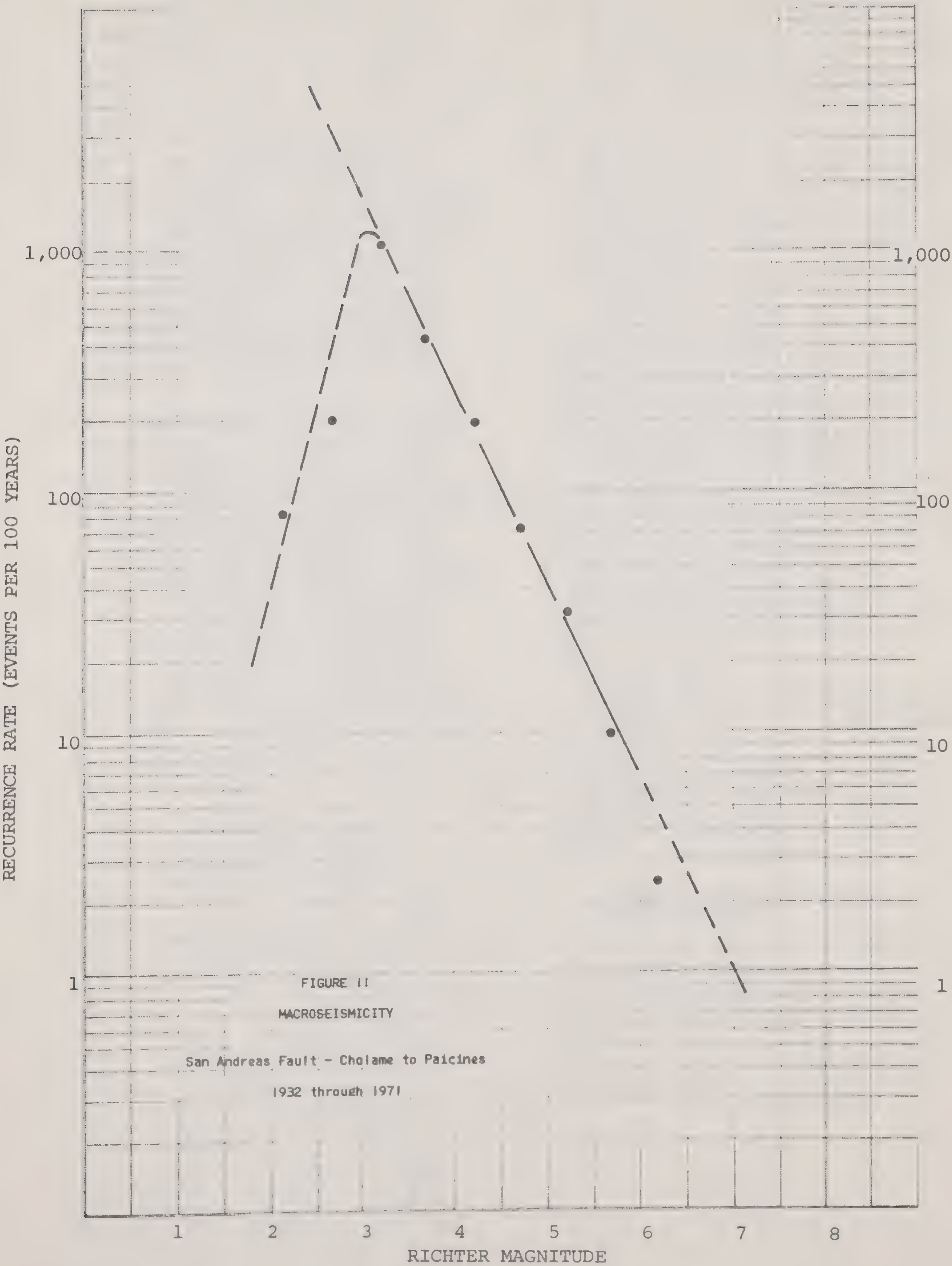


FIGURE 11

MACROSEISMICITY

San Andreas Fault - Cholame to Paicines

1932 through 1971

In addition to the actual slip along the fault, overall movement also includes the accumulation of strain in areas ranging up to tens of miles away from the fault. This strain accumulation can be compared to the bending of a large spring prior to its breaking - which is the earthquake. Strain accumulation and fault slip in the three areas of interest are summarized in Table 5. The critical relationships shown in the table are that the Central California active area is moving at 5-6 cm/year; that the Southern California active area is moving at 8.5 cm/year; but the area in between, the 1857 Break, shows no evidence of movement or strain accumulation. Since this segment was the source of the "great" Fort Tejon earthquake of 1857; and, since it would be imprudent to assume that the two ends could move without the segment in between moving eventually; it is only reasonable to conclude that stress is accumulating in the area of the 1857 Break at between 5 and 8.5 cm/year.

Of the above range of accumulating stress, the strain rate in the Central California active area is generally taken as applicable to the 1857 Break, with the difference of 2.5 to 3.5 cm/yr being accommodated in the Transverse Ranges at the southern end of the 1857 Break. While the 5-6 cm/yr rate for the Central California active area has been recently questioned (Savage and Burford, 1973), it is considered prudent to continue to use this rate until such time as there is an adequate explanation for a 70% decrease in strain that would be required along the San Andreas in the Transverse Ranges. It should also be noted that the 2 cm/yr fault slip discussed above for the area north of Parkfield would then account for the relief of only about 30% of the accumulating strain (Scholz and Fitch, 1970) in that area.

Recurrence intervals can be computed from the rate of strain accumulation using empirical relationships between the observed movement on a fault and the magnitude of the earthquake generated by that movement. Figure 12 is a plot of the relationship between these parameters for strike-slip faults based on data from Bonilla (1970). The displacement vs. magnitude relationship is converted to a recurrence vs. magnitude relationship for strain rates of 2, 4, 6 and 8 cm/yr in Figure 13. Since 116 years have elapsed since the last movement on the 1857 Break, the elapsed part of the recurrence interval is also shown. From these relationships it is apparent that, for the 6 cm/yr rate, sufficient strain (or stress) has already accumulated to generate an earthquake of magnitude 8.3. This is the estimated magnitude of the 1906 San Francisco earthquake. Also, it should be noted that even with the use of a lower rate, e.g. the 3.2 cm/yr of Savage and Burford (1973), a major earthquake (i.e. greater than magnitude 8.0) should be expected within the next 50 years on the segment of the San Andreas south of Cholame.

3. Geologic Slip

The basic concept that movement on the San Andreas fault during geologic time has amounted to several hundreds of miles has only been generally accepted among geologists for approximately 15 to 20 years. Before that time, the scope of the work of any one geologist or any group of geologists was not adequate to recognize the very large offsets involved. It was only after the completion of detailed geologic mapping of most of the western half of the State that the true "picture" became apparent. However, as with most "revolutionary" concepts, once proposed, the volume of corroborative data has been overwhelming.

The status of knowledge up to approximately 1972 on geologic slip on the San Andreas fault is summarized in Figure 14. This graph of movement vs. geologic time (in millions of years before the present) indicates that the rate of movement has been increasing over the last 25 million years from near zero to a rate approaching 6 cm/yr. More recent work (e.g. Clarke and Nilsen, 1973, and Huffman, Turner and Jack, 1973) has tended to corroborate this increase in the rate of movement over the last 25 million years, and to confirm that there was a period before that (approximately 50 to 25 million years before present) when essentially no movement occurred on the San Andreas as we know it today.

Investigations of a different sort by Molnar and Atwater (1973) based on plate tectonics and sea-floor spreading indicate a significant acceleration in the rate of movement for more recent time intervals. They propose a 5.7 cm/yr rate for the last 10 million years. This rate is consistent with the 6 cm/yr rate for present-day strain accumulation, but is inconsistent with some geologic data.

4. Summary of Recurrence Analysis for San Andreas Fault

The recurrence curves from the analysis of microseismic and macroseismic data are combined on Figure 15. The data from the former are more accurate in the magnitude range of 2.5-4.0 while the latter are more accurate in the range of 4.0-5.5. The curves are very similar with some suggestion of an increase in the expected rate for the events of smaller magnitude.

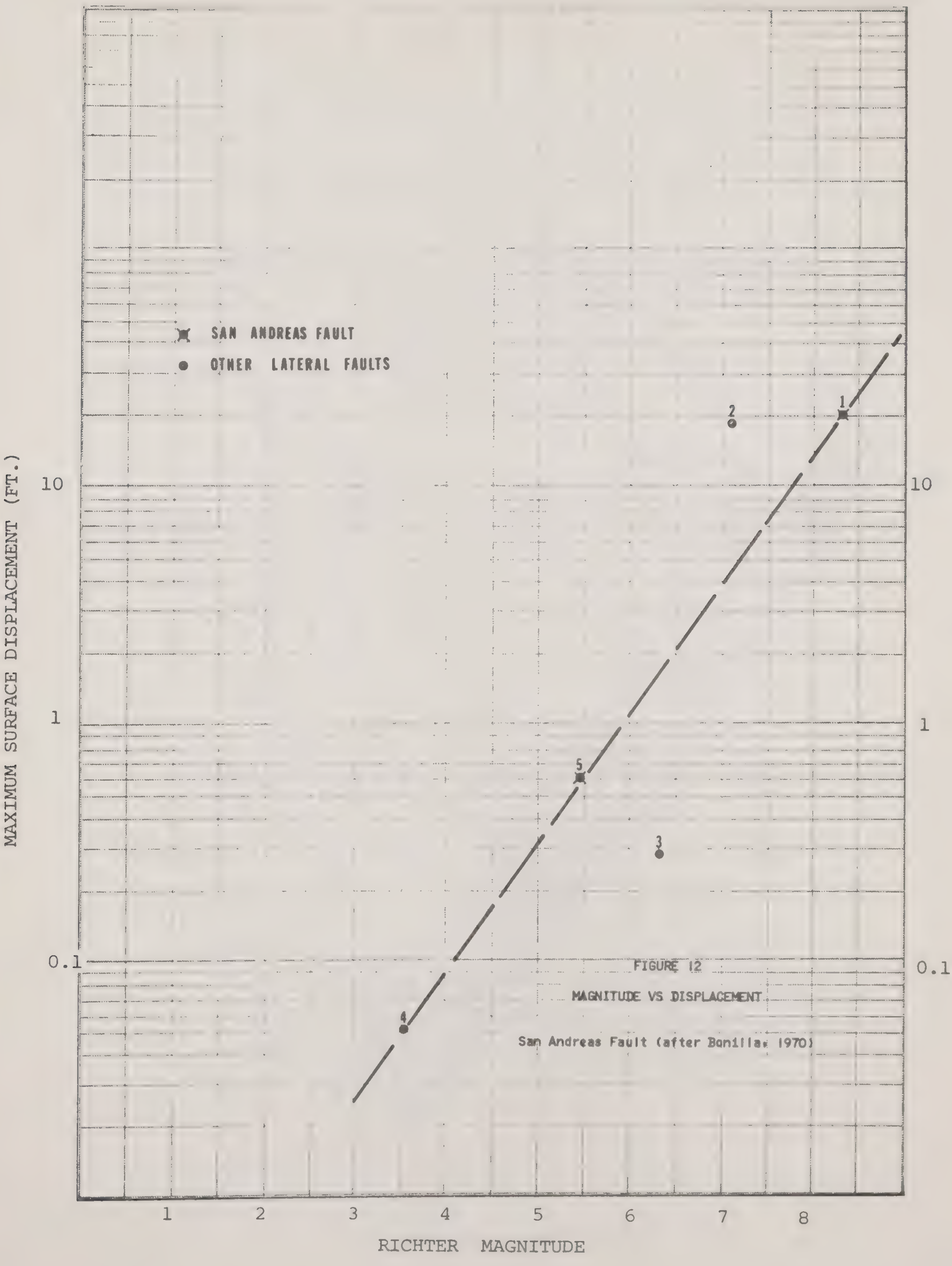


FIGURE 12

MAGNITUDE VS DISPLACEMENT

San Andreas Fault (after Bonilla, 1970)

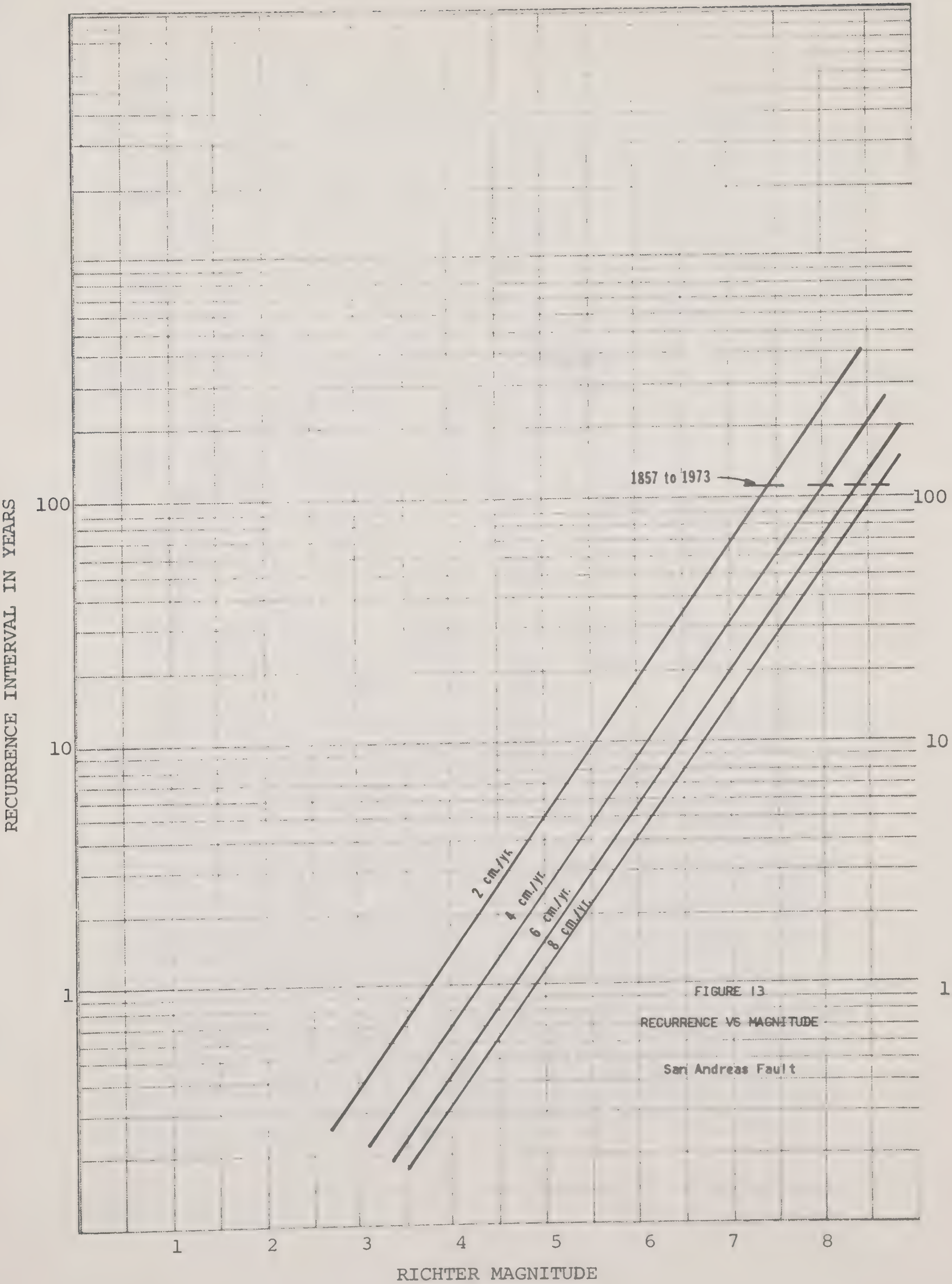


FIGURE 13

RECURRENCE VS MAGNITUDE

San Andreas Fault

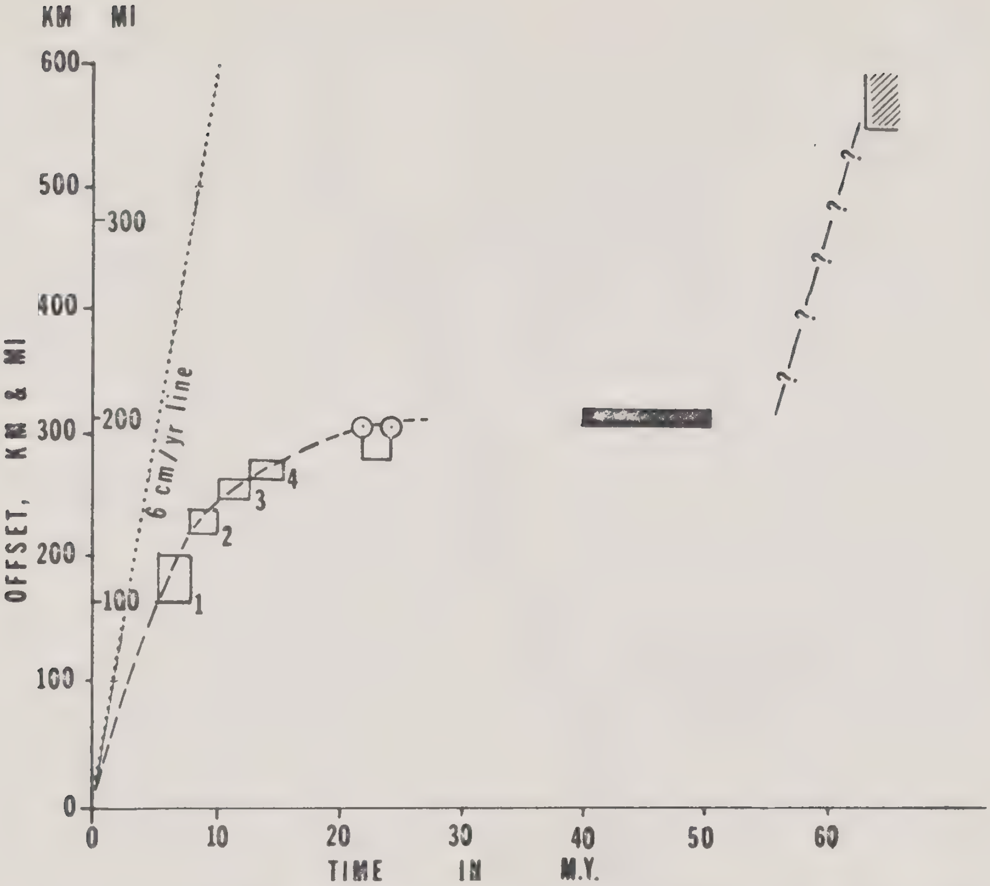


Fig. 14 - Offset-time grid. Three curves are shown: (a) Dotted line represents 6 cm/year, inferred from oceanographic data as current overall strain rate for complex San Andreas transform system as whole (Atwater, 1970). (b) Dashed line is hypothetical offset history of late Cenozoic San Andreas fault drawn to pass through following check points discussed in text (boxes enclose age span inferred here and uncertainty in amount of apparent offset): 1, lower Pliocene rocks (our estimate); 2, uppermost Miocene (Delmontian?) rocks (our inference from Pinnacles-Parkfield-Neenach felsite relations noted by Huffman, 1970); 3, lower upper Miocene (Mohnian?) rocks (after Fletcher, 1967, and Huffman, 1970); 4, middle Miocene rocks (our interpretation after Addicott, 1968); 5, lower Miocene volcanic rocks dated at 21.5 and 23.5 m.y. old (circles indicate most likely offset indicated by Huffman, 1970). Curve is drawn nominally, to begin 25-30 m.y. ago and to approach 6 cm/year line smoothly and asymptotically, but uncertainties in check points, except at 21.5 and 23.5 m.y. ago, might permit younger part of line to be steeper, and region of greatest curvature to be sharper and younger. (c) Queried line indicates speculative time of offset on early Cenozoic (?) "proto-San Andreas" fault (Suppe, 1970). Line is drawn on assumption that certain Eocene rocks (see text), represented roughly by black bar, are offset about 200 mi. Ruled rectangle in upper right corner roughly indicates post-Cretaceous offset in Coast Ranges. Slope of queried line depends heavily on Eocene tie, for which results are suggestive but incomplete (T. Nilsen and S. H. Clarke, work in progress).

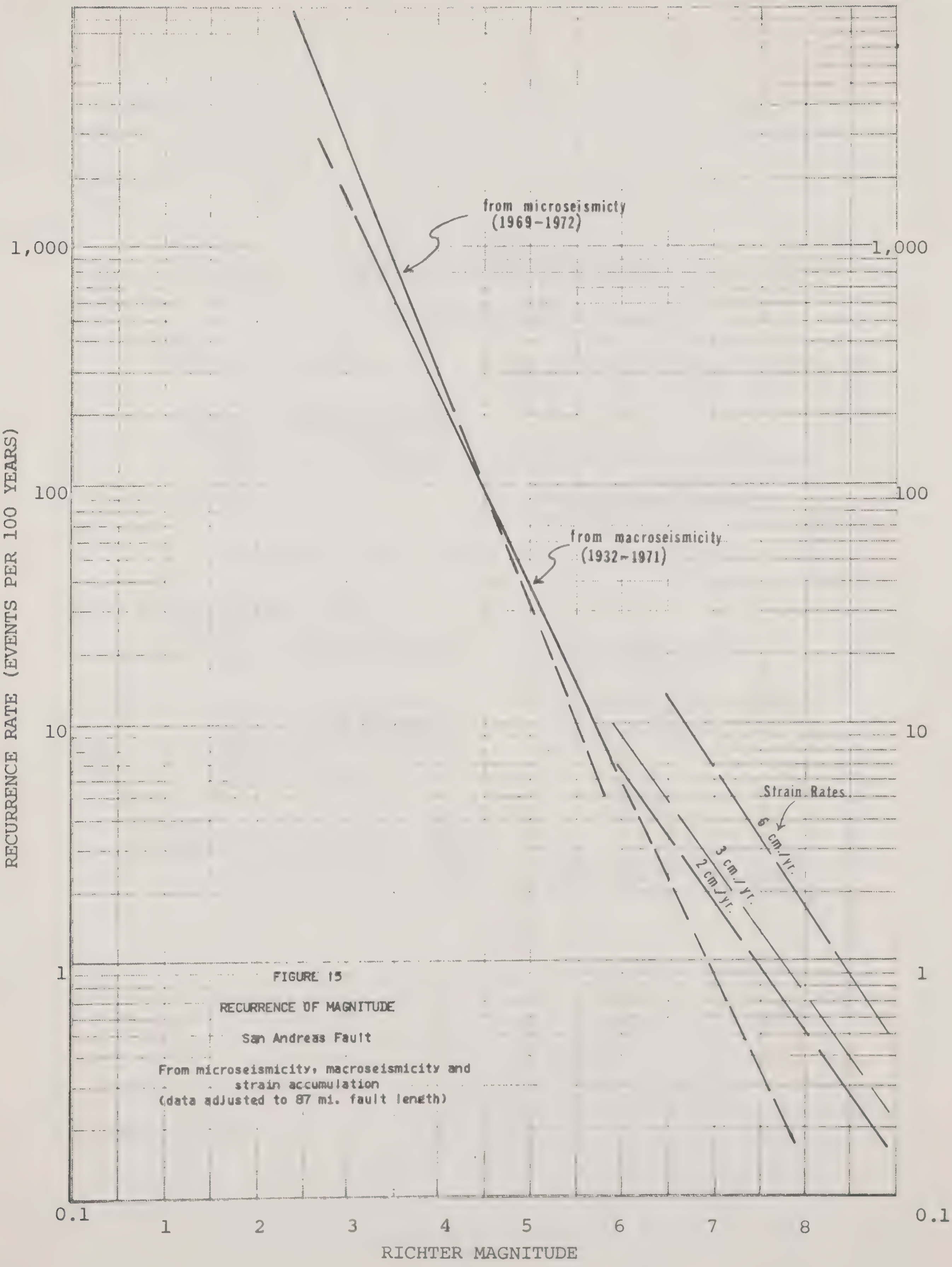


FIGURE 15

RECURRENCE OF MAGNITUDE

San Andreas Fault

From microseismicity, macroseismicity and strain accumulation (data adjusted to 87 mi. fault length)

TABLE 5
STRAIN ACCUMULATION AND FAULT SLIP
CENTRAL AND SOUTHERN SAN ANDREAS FAULT

(From Greensfelder, 1972)

Area and Triangulation Net	Strain Accumulation and Fault Slip
1. Central California Active Area:	
a. San Francisco Bay Area, 1906 - 1969	5 - 6 cm/yr displacement between Mt. Diablo and San Francisco Penninsula; both strain and fault slip.
b. Salinas River, 1944 - 1963	3 cm/yr slip on San Andreas fault.
2. Area of 1857 Break:	
a. San Luis Obispo to Avenal, 1932 - 1951	1.5 cm/yr slip and strain.
b. Gorman, 1935 - 1956; Palmdale, 1938 - 1958; Cajon Pass, 1949 - 1963; Newport Beach to Riverside, 1929 - 1953	No significant movement detected.
3. Southern California Active Area:	
a. Imperial Valley, 1941 - 1967	8.5 cm/yr regional displacement.

The inclusion on the graph of the rate derived from strain accumulation requires additional explanation. As was noted previously, the rates derived from seismicity apply to an 87 mile segment of the fault. If a larger segment having the same level of activity had been used, the rates would have been higher. Since the larger earthquakes normally involve rupture surfaces larger than 87 miles, rates must be corrected to the 87-mile length if they are to be compared to the seismicity data. This correction is based on empirical relationships developed by Bonilla (1970), listed in Table 6 and plotted on Figure 16. Using these relationships, strike-slip movement accompanying a magnitude 8.3 earthquake on the San Andreas fault would be expected to occur along a length of approximately 200 miles. Correction of the recurrence rates discussed previously for a "great" earthquake (M=8.3) are as follows:

Strain Rate (cm/yr)	True Recurrence Rate (Events/ 100 yrs)	Effective Recurrence Rate for 87-mile Segment (Events/ 100 yrs)
6	0.985	0.428
3	0.492	0.214
2	0.326	0.143

Similar corrections for a "large" earthquake (M=7.0) with a surface rupture of 68 miles (Figure 16) are as follows:

Strain Rate (cm/yr)	True Recurrence Rate (Events/ 100 yrs)	Effective Recurrence Rate for 87-mile Segment (Events/ 100 yrs)
6	5.19	6.64
3	2.59	3.32
2	1.73	2.21

The effective recurrence rates computed above are plotted on Figure 15 for comparison with the rates developed from the seismicity of the active segment of the fault. These data and the relationships discussed in the previous sections indicate the following with regard to the recurrence rates for a major, damaging earthquake on the San Andreas fault:

1. Extrapolation of the curve developed from macroseismic data yields recurrence rates that are less than that from a strain rate of only 2 cm/yr.

2. Extrapolation of the curve developed from microseismic data yields recurrence rates that are even less than those from the macroseismic data.

3. Since the minimum strain rate appears to be approximately 3.2 cm/yr and a more prudent choice would be the 6 cm/yr rate, the latter is recommended as the rate on which to base the risk of a major earthquake on the 1857 Break of the San Andreas fault.

4. At 6 cm/yr, the recurrence interval for a magnitude 8.3 earthquake is only slightly in excess of 100 years. Since 116 years have elapsed since the last "great" earthquake or this segment, a major earthquake can be considered as imminent.

5. Even at the smaller strain rate of 3 cm/yr, a major earthquake (M=8.3-8.5) should be expected sometime in the next 100 to 150 years.

6. The variation in recurrence rates for major earthquakes as developed from the three data sources suggests an increase in the efficiency of energy release for major earthquakes, as opposed to the small and intermediate sized earthquakes that characterize the active areas.

c. Owens Valley Fault Group

1. Seismicity

Earthquake epicenters for the Owens Valley fault group for the period 1932 through 1971 are shown on Plate I. They show a concentration in the general area of the Valley and also in the area of volcanic activity between Bishop and Mono Lake. A potentially important characteristic of the areal pattern of the epicenters in the relatively small number of events in the area between Bishop and Owens Lake. This is the area of fault rupture during the "great" Owens Valley earthquake of 1872, and the lack of recent epicenters can be attributed to the release of the accumulated strain in that year. An important corollary of this observation is that the "quiet zone" is not limited to the area of the fault rupture, but extends to the northeast and southwest across the trend of activity. This suggests that although the epicenters in this area are scattered over a wide area, they are related to the zone of active faulting along the east side of the Sierra Nevada.

Because of these differences in the level of activity, the Owens Valley fault zone is divided into three areas: a "north area" that includes the earthquake activity near Bishop and to the north; a "central area" that is seismically quiet; and a "south area" that includes the area of the study south of the "quiet" zone. In addition to this subdivision, the overall trend has been divided into a near zone that includes the highest concentration of events, and wide zone that includes essentially all the events that appear to be related to the faulting on the east side of the Sierra Nevada. The limit of the near zone

TABLE 6

Faults Used in Constructing Figure 16.

No.	Fault	Year	Magnitude	Length (Mi.)
1	San Andreas	1906	8.3	270
2	Imperial	1940	7.1(6.5±)	40+
3	Manix	1947	6.4	1
4	Superstition	1951	5.6	2
5	Fairweather	1958	8.0	115-124
6	Imperial	1966	3.6	6
7	San Andreas	1966	5.5	23
8	Owens Valley	1872	8.3±	60±
9	Pleasant Valley	1915	7.6	20-40
10	Cedar Mountain	1932	7.3	38
11	Excelsior Mtns.	1934	6.5	0.9
12	Fort Sage	1950	5.6	5.5
13	Rainbow Mountain	(July) 1954	6.6	11
14	Rainbow Mountain	(August) 1954	6.8	19
15	Fairview Peak	1954	7.1	36
16	Dixie Valley	1954	6.8	38
17	San Miguel, Mex.	1956	6.8	12+
18	Hebgen Lake	1959	7.1	15

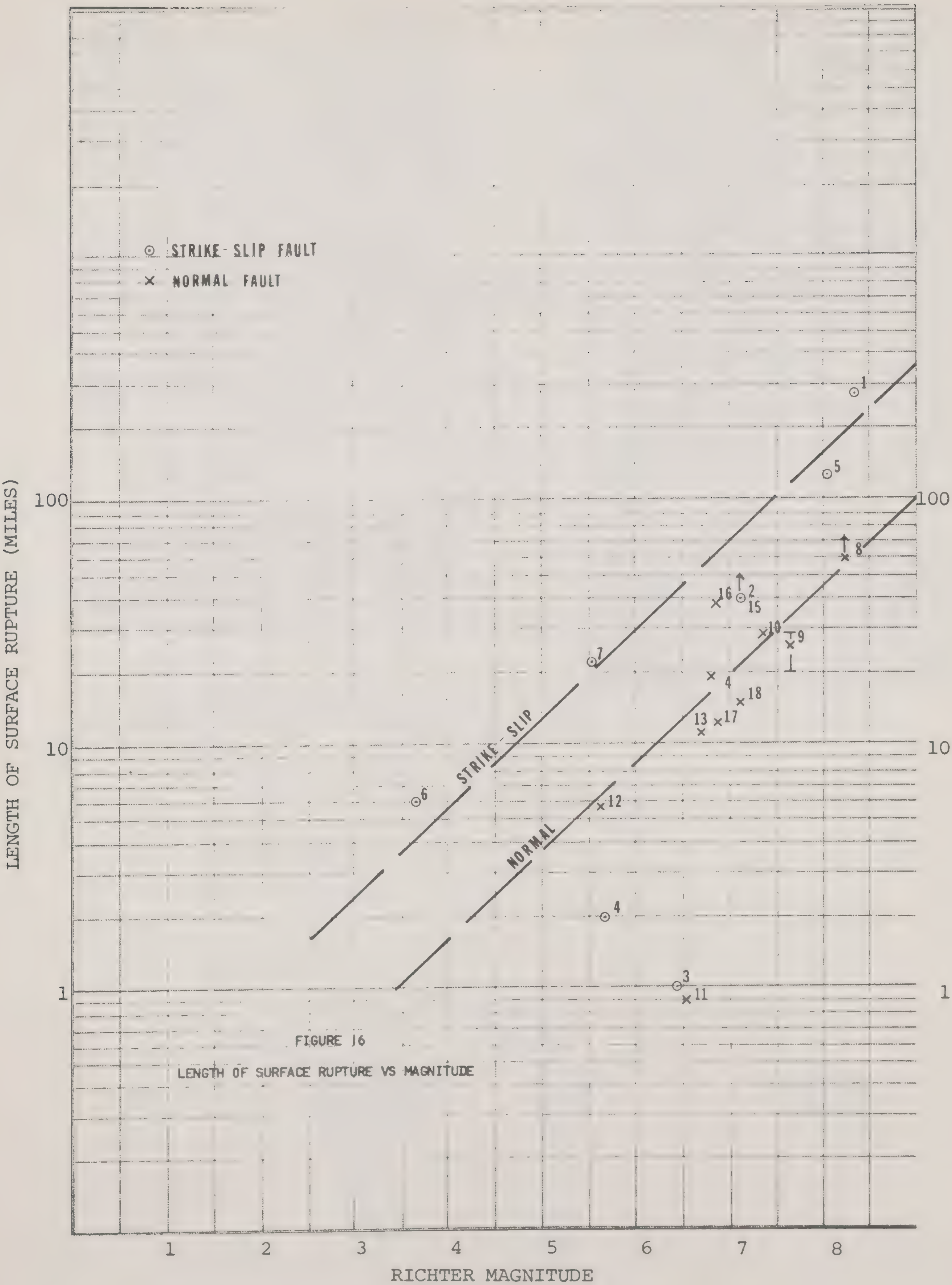


FIGURE 16

LENGTH OF SURFACE RUPTURE VS MAGNITUDE

is shown on Plate I, and the data are summarized by zone in Table 7. The plotting procedure and the reliability characteristics are the same as discussed for the San Andreas fault. The recurrence plot for the "north area" is shown on Figure 17, and the "south area" on Figure 18. The "central area" does not include sufficient epicenters to warrent analysis.

The recurrence rates for the larger, potentially damaging earthquakes from these two areas are summarized below. The maximum probable earthquake considered is arbitrarily limited to one magnitude level above the largest recorded earthquake. The resulting magnitudes are consistent with those proposed tentatively by Greensfelder (1973) for the "north area;" he does not distinguish the "south area" from the "central area," and proposes a magnitude of 8.25 for the latter.

2. Crustal Strain

A triangulation network across the Owens Valley fault in the "central area" has been surveyed in 1935 and 1956 with no significant movement detected. This is the fault that moved in 1872, and it has apparently not experienced any recent creep or adjustment.

3. Geologic Slip

Data on offsets of unique geologic units such as those that have been compiled for the San Andreas fault are not available for the Owens Valley area. However, a very rough estimate of the recurrence of vertical movement can be made using data on the age of the topographic relief of the east slope of the Sierra Nevada. Webb (1946) in his study of the erosion surfaces of the middle Kern River Basin concluded that relief during the Pliocene amounted to approximately 4000 feet. Dalrymple (1963) has dated some of the volcanic flows associated with these erosion surfaces with results of approximately 3.5 million years before the present. Assuming the Quaternary valley fill extends to near sea level, the increase in relief in the last 3.5 million years is approximately 10,000 feet. The vertical displacement for the 1872 earthquake was 23 feet (Bonilla, 1970). Assuming an equal distribution of movement through time, similar movements occurring at intervals of approximately 8,000 years (3.5 million years [10,000 feet ÷ 23 feet]) would be required to produce the present relief.

An alternative method is suggested by unpublished data of Dr. David B. Slemmons of the University of Nevada. His detailed work along an alluvial fan faulted during the 1872 earthquake indicates two additional episodes of movement comparable to the 1872 movement during a period of 40,000 to 60,000 years. The indicated recurrence interval is 13,000 to 20,000 years.

Recurrence

Area	Rate (Events per 100 yrs)	Interval (years)	Magnitude (Richter)
North	2.0	50	6.5
	0.8	125	7.0
South	2.0	50	5.6
	0.75	135	6.0

TABLE 7
MACROSEISMICITY OF THE OWENS VALLEY FAULT ZONE
1932 through 1971

Number of Events

	"North Area"				"South Area"				TOTAL			
	Near Zone		Wide Zone		Near Zone		Wide Zone		Near Zone		Wide Zone	
Magnitude	40yrs.	100yrs.	40yrs.	100yrs.	40yrs.	100yrs.	40yrs.	100yrs.	40yrs.	100yrs.	40yrs.	100yrs.
1.0-1.4	--	--	--	--	1	2.5	1	2.5	1	2.5	1	2.5
1.5-1.9	--	--	--	--	8	20.0	8	20.0	8	20.0	8	20.0
2.0-2.4	2	5.0	3	7.5	22	55.0	24	60.0	24	60.0	27	67.5
2.5-2.9	7	17.5	13	32.5	34	85.0	39	97.5	41	102.5	52	130.0
3.0-3.4	115	287.5	152	380.0	92	230.0	125	312.5	207	517.5	277	692.5
3.5-3.9	78	195.0	120	300.0	59	147.5	72	180.0	137	342.5	192	480.0
4.0-4.4	69	172.5	105	262.5	19	47.5	24	60.0	88	220.0	129	322.5
4.5-4.9	18	45.0	31	77.5	3	7.5	4	10.0	21	52.5	35	87.5
5.0-5.4	5	12.5	7	17.5	2	5.0	2	5.0	7	17.5	9	22.5
5.5-5.9	2	5.0	3	7.5	--	--	--	--	2	5.0	3	7.5
6.0-6.4	2	5.0	2	5.0	--	--	--	--	2	5.0	2	5.0

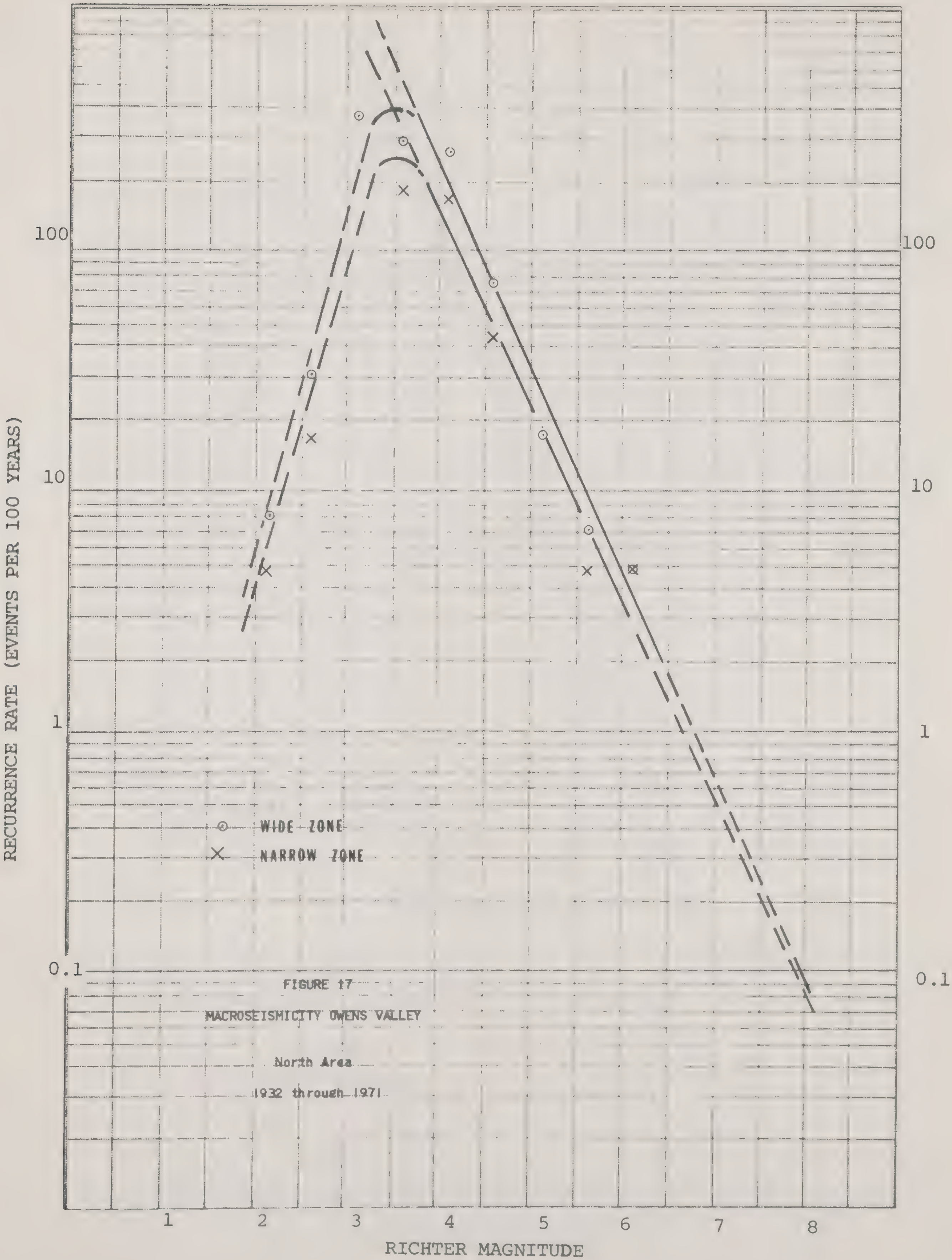


FIGURE 17

MACROSEISMICITY OWENS VALLEY

North Area

1932 through 1971

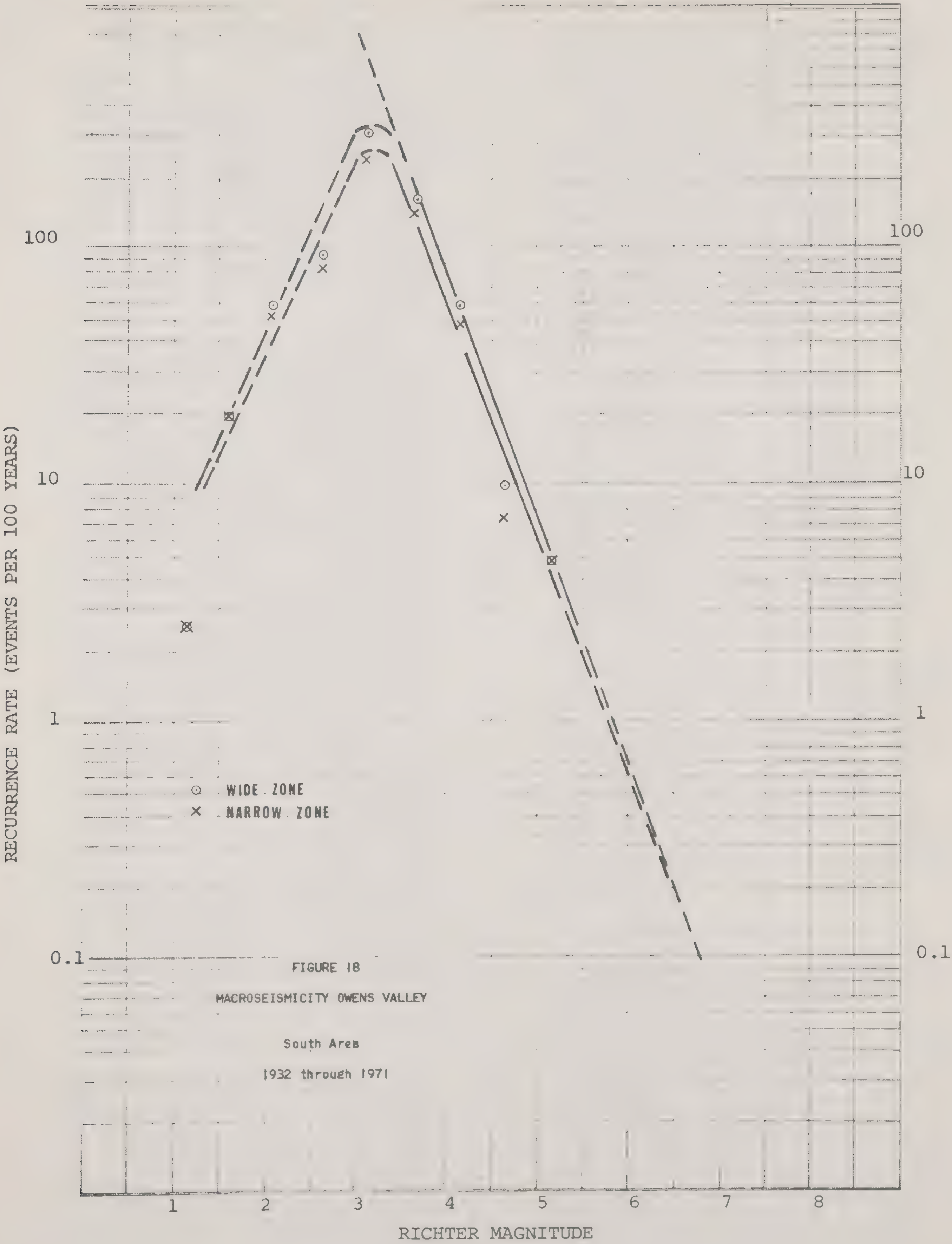


FIGURE 18

MACROSEISMICITY OWENS VALLEY

South Area

1932 through 1971

4. Summary of Recurrence Analysis for Owens Valley Fault Group

Recurrence rates can be established for the more active "north area" and "south area" using epicenter data. The "central area," however, appears to be similar to the 1857 Break on the San Andreas fault in that it is quiet seismically but has been the source of one of California's three "great" earthquakes during historic time. The problem is not will it move again; we must assume it will. The problem is to determine a credible level of risk to aid in determining the appropriate action.

The data are not adequate for a direct solution of this problem, but what is available suggests an analogy to the San Andreas fault. If the results of the analysis of the several types of data for the San Andreas are applied to the Owens Valley fault, the recurrence rate for the "central area," should be at least as large, and probably larger than the adjacent active areas. Applying this logic, recurrence rates for the maximum probable earthquake of magnitude 8.25 (Greensfelder, 1973) should be at least in the range of 0.065 (Figure 17) to less than 0.01 (Figure 18) events per 100 years (i.e. recurrence interval of 1500 to more than 10,000 years). While consideration of the geologic slip rate would tend to favor the larger recurrence interval, the increased efficiency of energy release that is suggested for the San Andreas fault would favor a shorter recurrence interval. A direct relationship between the two faults should not be expected because the mechanical characteristics of the two faults are quite different. However, since the seismicity of the active areas are both less than those of the San Andreas fault, the recurrence intervals are probably longer. On this basis, the recurrence interval for the expected magnitude 8.25 earthquake is estimated at somewhere in the range of 300 to 10,000 years. It should be emphasized that this range is strictly a "ball park" estimate. The data are not adequate for a more accurate determination.

d. White Wolf Fault

The White wolf fault was essentially unknown as an active fault until the 1952 earthquakes in Kern County. The investigations that followed showed clearly that had the fault been investigated for potential activity, there would have been, at a minimum, a much greater level of concern. The problem was that there was no obvious sign of activity. Seismicity was low befor the earthquake and its many aftershocks, and there were no known creep or small movements on the fault in the years prior to the earthquake. Thus, the seismicity of the area is limited to a single event and its aftershocks, and is not adequate for recurrence analysis. Left-lateral creep of 1.3 cm/yr is now reported along the fault (California Division of Mines and Geology, 1972), but this can be considered an after effect of the 1952 earthquake sequence.

Geologic slip has been used by Lamar, Merifield & Proctor to estimate the recurrence interval for a magnitude 7.0 earthquake of approximately 1,000 - 5,000 years. While experience with the San Andreas fault suggests that geologic slip rates, averaged over several millions of years, may be less than rates occurring today, there is little other data with which to refine the estimate.

e. Summary of Recurrence Analysis

The objective of the recurrence analysis for the known active faults that could generate damaging earthquakes in the Five-County area has been to establish, as accurately as possible, the average time intervals that should be expected between major earthquakes. Where possible, several methods have been discussed. These have been included not only to serve as rough checks on the most reliable method, but also to emphasize the wide range of values that can be obtained depending on the information that is available.

The recurrence rates or intervals developed in the preceding sections are intended to describe seismic risk. As discussed in the Introduction, the recurrence of earthquakes can be used to describe the risk of an earthquake occurring in much the same manner that the recurrence of floods is used to describe the risk of a flood occurring. In this context, the magnitude of the "100-year earthquake" or the "300-year earthquake" can be obtained directly from the recurrence plots in the preceding sections.

Values obtained in this manner, however, can be very misleading. We have seen in the previous sections that individual segments of the major faults are relieving the accumulating strain in different ways. The active segments are relieving this strain as many small-to-moderate magnitude earthquakes. These segments are less likely to be the source of a "great" earthquake. In the same context, the seismically "quiet" segments appear to be storing energy, which most likely will be released, as it has in the past, as a "great" earthquake. These relationships cannot be said to be proven in the scientific sense; the seismic record is too short to be absolutely sure. They are, however, logical relationships that suggest the magnitude of the "maximum probable" earthquake that should be expected from a particular fault segment in the future.

The maximum probable earthquake and its recurrence rate and recurrence interval are summarized in Table 8 for each of the major fault segments discussed in the previous sections. The choice of the maximum probable magnitude is based on the concepts discussed above, and the recurrence is based on the data developed in the previous sections. If the year of the last occurrence of the maximum probable earthquake is known for a particular segment, the time remaining in the recurrence interval is also shown. It is emphasized that the inclusion of this last item is not meant to imply the prediction of an earthquake in a particular year; and is included only to remind the reader that a substantial part of some recurrence intervals have elapsed.

3. Intensity of Recorded Earthquakes

a. General Statement

A general description of some of the more important earthquakes that have resulted in strong shaking in the Five-County area are included to: 1) document the levels of shaking that have occurred in the past and which should be expected in the future; and, 2) to investigate local variations in shaking that can be used as a "rough check" of the microzonation that will be developed by an independent method. For this reason, isoseismal maps have been constructed for each of the more important earthquakes for which data are available. These maps show the areal variation in the intensity of earthquake shaking as described by the standard intensity scales described in the Introduction. All the maps are based on the Modified Mercalli Scale of 1931 except the San Francisco earthquake of 1906, which is based on the Rossi-Forel scale that was in use at that time. The equivalent Rossi-Forel levels are given in the description of the Modified Mercalli Scale in the Introduction.

b. San Francisco Earthquake of 1906

The San Francisco earthquake of 1906 is undoubtedly the most important earthquake to have affected the Five-County area during historic time. It was investigated in great detail by geologists, seismologists, and engineers of the State Earthquake Investigation Commission, and the results of this investigation have served as the basis for much of our understanding of the relationship between earthquakes and faulting. The importance of this earthquake to our understanding of future earthquakes in the Five-County area is that it is the only "look-alike" for the "great" earthquake that is expected along the 1857 Break of the San Andreas fault. Had the 1857 quake itself been studied in the detail that was given to the 1906 event, it would have been the most important event. However, very little is known about this earthquake that is useful for the objectives stated above.

The 1906 earthquake occurred as the result of rupture along the San Andreas fault from Cape Mendocino to near Hollister (Figures 7 and 8). Intensities of shaking as mapped by Lawson, et al (1908, Plate 23) for the State, and included here for the Five-County area and vicinity as Figure 19, show the following variations significant to our understanding of shaking to be expected in the Five-County area:

1. Shaking reached a maximum of intensity X (Rossi-Forel) near the zone of fault rupture and generally decreased with increasing distance from the fault.

2. Local variation from the overall decrease with distance can be generalized as a decrease in areas underlain by firm bedrock and an increase in areas underlain by alluvium.

3. Examples of increased shaking in the alluvial valleys in or near the Five-County area are (Figure 19) the Salinas Valley, Priest Valley, and the west-central San Joaquin Valley between Los Banos and Coalinga.

4. The latter is the most prominent local anomaly in the State, with Intensity IX at Los Banos and VIII to IX in the Coalinga area more than 80 miles from the nearest point on the fault rupture. This is in striking contrast to intensities as low as V on firmer ground in the Santa Cruz area about 15 miles from the fault break.

5. The high intensities on the west side of the Valley give way rapidly to a broad zone of Intensity VI - VII and a narrower zone of Intensity V - VI near the foothills of the Sierra Nevada.

6. Intensities in most of the Five-County part of the Sierras were a near constant IV - V.

A similar pattern of shaking should occur during the expected magnitude 8.3 - 8.5 earthquake on the 1857 Break of the San Andreas fault, except that intensities will probably be higher in the south because of the proximity of the 1857 Break to that part of the Five-County area.

FIGURE 19

ISOSEISMAL MAP

San Francisco Earthquake of 1906

(Data from Lawson et al., 1908)

GRAPHICS BY TULARE COUNTY PLANNING DEPARTMENT

TABLE 8
SUMMARY OF RECURRENCE OF MAXIMUM
PROBABLE EARTHQUAKES FOR THE FIVE-COUNTY AREA

Fault and Segment	Richter Magnitude of Maximum Probable Earthquake	Recurrence Rate (Events per 100 yrs)	Recurrence Interval (years)	Year of Last Occurrence of Maximum Probable Earthquake	Time Remaining in Recurrence Interval (years)
San Andreas fault:					
1857 Break	8.3-8.5	0.98-0.65[1]	102-155	1857	0-40
Transition zone	8.1-8.3[2]	0.98-0.65[1]	102-155	1857	0-40
Active area	7.0	1.0	100	--	--
Owens Valley fault group:					
North area	7.0	0.8	125	--	--
South area	6.0	0.75	135	--	--
Central area (Owens Valley fault)	8.25	0.065-0.01	300 - 10,000	1872	200 - 10,000
White Wolf fault	7.0	--	1,000 - 5,000	1952	1,000 - 5,000

[1]Based on strain rate of 6 cm/yr.

[2]Assumes release of accumulated strain at 4 cm/yr not accounted for in known slip.

c. Recent Earthquakes on the San Andreas Fault

Isoseismal maps (Figures 20-22) have been prepared from data in United States Earthquakes for the three largest earthquakes that have occurred on the San Andreas fault since 1928 when the compilation of detailed records was begun in the area. These maps generally confirm the observations of local variation as noted previously for the 1906 earthquake. As with most earthquakes of this magnitude (5.5 - 6.0), intense shaking (greater than VII to VIII) is limited to a relatively small area near the epicenter, with only moderate to barely perceptible shaking in most of the Five-County area. Earthquakes of this magnitude should be expected from the transition zone of the San Andreas fault at intervals averaging approximately 10 years (Figure 15).

d. Owens Valley Earthquake of 1872

The Owens Valley earthquake of 1872 is one of the three "great" earthquakes of California recorded history. The magnitude has been estimated at between 8.0 and 8.3 with the larger being the more likely (Oakshott, Greensfelder and Kahle, 1972). Ground rupture (Plate I) extended from south of Owens Lake to near Bishop (California Geology, 1972). Records of the intensity were not kept at that time, but an isoseismal map (Figure 23) has been compiled by Greensfelder (Oakshott, Greensfelder and Kahle, 1972) from newspaper accounts. This map indicates intensities (Modified Mercalli) of VII-VIII on the east side of the San Joaquin Valley near the foothills, and intensities as high as VIII in the mountain valleys of the Sierra Nevada.

e. Recent Earthquakes on the Owens Valley Fault Group

Isoseismal maps (Figures 24 and 25) have been prepared from data in United States Earthquakes for the two largest earthquakes that have occurred in the Owens Valley area since the compilation of detailed records was begun in 1928. These maps do not show the high intensities in the epicentral area as was noted for the San Andreas earthquakes of the same magnitude (5.5-6.0). This can be attributed to a greater focal depth and possibly also to a more disbursed population in the area. Higher intensities in the Five-County area are limited to some valleys in the Sierras and to some east-valley locations at or near Fresno and in south-central Tulare County. The decrease in intensity through the dominantly granitic bedrock of the Sierra Nevada is apparently low, and intensities in the east Valley are not significantly lower than those in the Owens Valley much nearer the epicenter.

f. Arvin-Tehachapi Earthquake of 1952

The Arvin-Tehachapi earthquake of July 21, 1952 occurred as the result of movement on the White Wolf fault located south of Bakersfield. This fault is not as important as the source of major earthquakes or are the San Andreas and Owens Valley faults, but this particular earthquake is one of the most severe in the area for which detailed intensity data are available. This data is particularly significant in that the source of the shaking is to the south of the Five-County area, and is oriented in such a way that, other conditions being equal, intensities along lines oriented northeast-southwest should be equal. Thus, variations in observed intensities in this direction should be a good indication of the variations in local conditions that will influence the microzonation of the area.

The intensity data for this earthquake are shown on two maps; the generalized distribution is shown on the published map by the Coast and Geodetic Survey (Neumann and Cloud, 1955) reproduced here as Figure 26, and the detail in the Five-County area from United States Earthquakes is shown on Figure 27. Variations in observed intensity pertinent to the Five-County area are as follows:

1. The Coalinga area is high in comparison to the bedrock areas to the west and slightly lower than the alluvial areas of western San Joaquin Valley to the east.

2. The extreme southwestern side of the Valley experienced higher intensities, relatively, than the east side of the valley, except in western Kings County. The trend of higher intensities in northwestern Kern County gives way to the northwest to lower intensities in the Tulare Lake area.

3. Intensities in the Sierra Nevada are comparable to those in the Valley, and are locally high in some mountain valleys such as Yosemite.

GRAPHICS BY TULARE COUNTY PLANNING DEPARTMENT

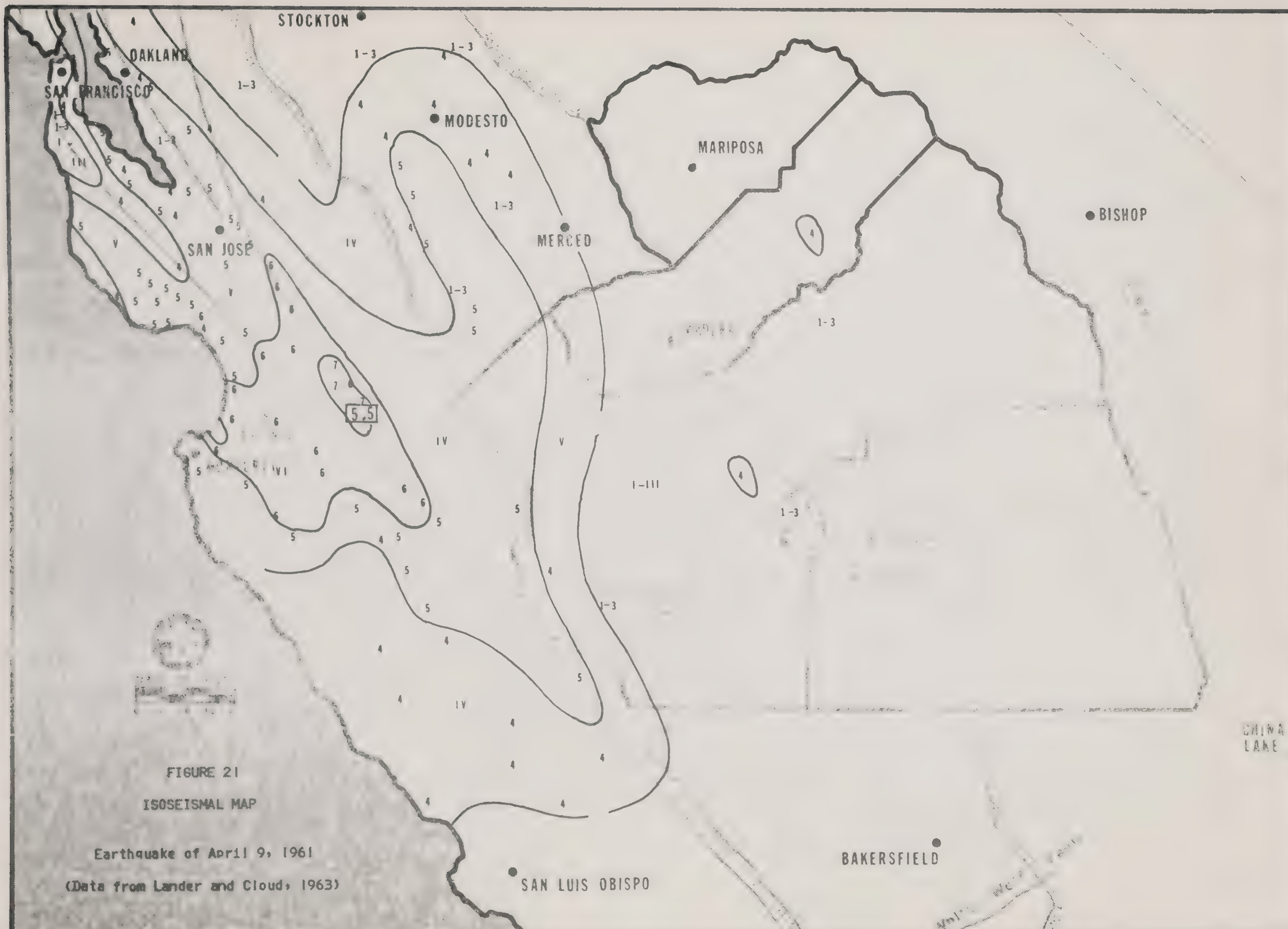


FIGURE 21

ISOSEISMAL MAP

Earthquake of April 9, 1961

(Data from Lander and Cloud, 1963)

GRAPHICS BY TULARE COUNTY PLANNING DEPARTMENT

FIGURE 7.

ISOSEISMAL MAP

Earthquake of June 28, 1966

(Data from von Hake and Cloud, 1968)

GRAPHICS BY TULARE COUNTY PLANNING DEPARTMENT

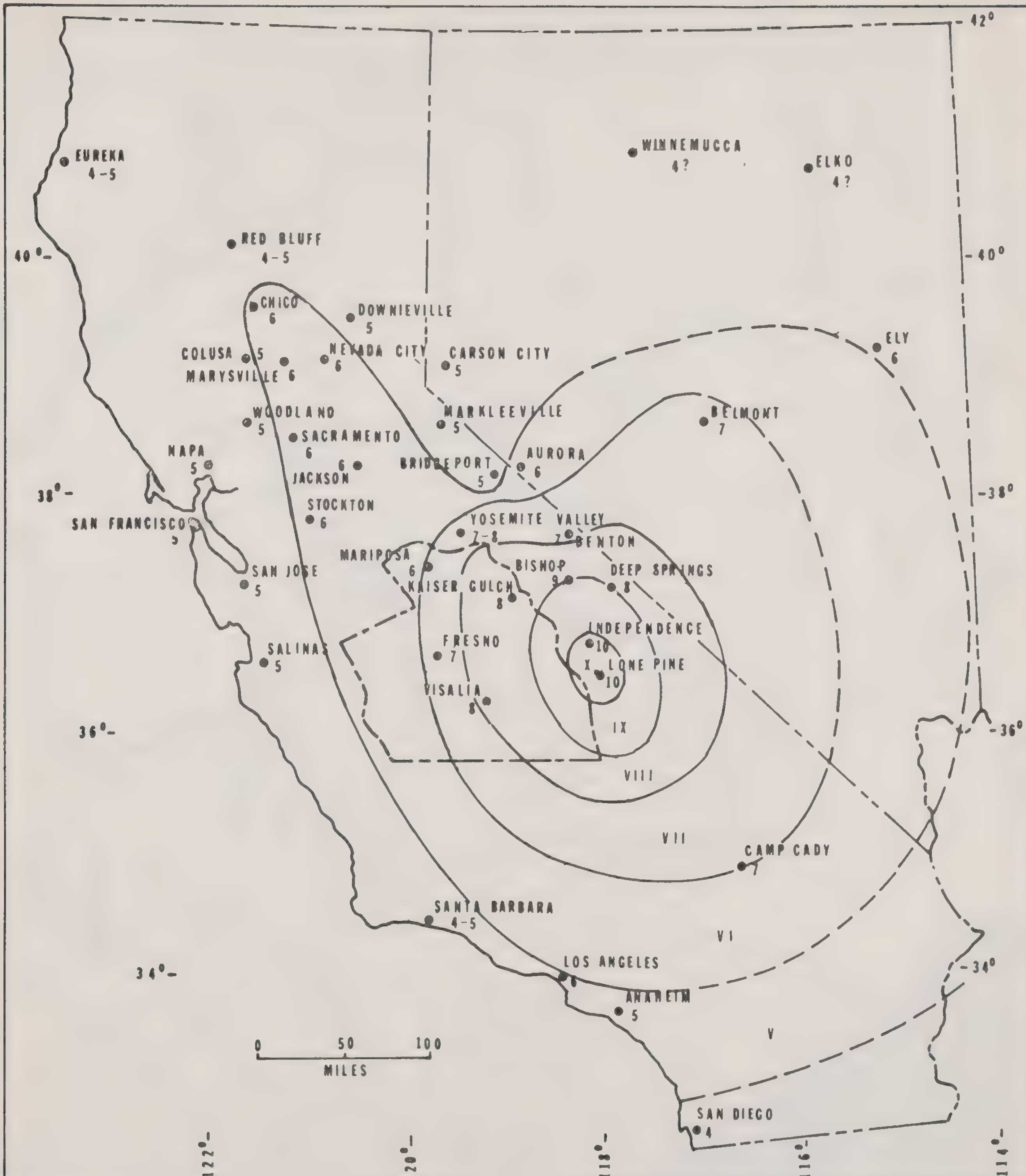


FIGURE 23. Isoseismal map of Owens Valley earthquake of 1872. Towns marked are those from which newspaper accounts were obtained. Arabic numerals give intensities at specific localities; Roman numerals give zonal intensities. All intensities are on Modified Mercalli intensity scale. Map compiled by Roger W. Greensfelder.

From Oakshott, Greensfelder & Kahle, 1972.

FIGURE 24

ISOSEISMAL MAP

Earthquake of December 3, 1938

(Data from Neumann, 1943)

GRAPHICS BY TULARE COUNTY PLANNING DEPARTMENT

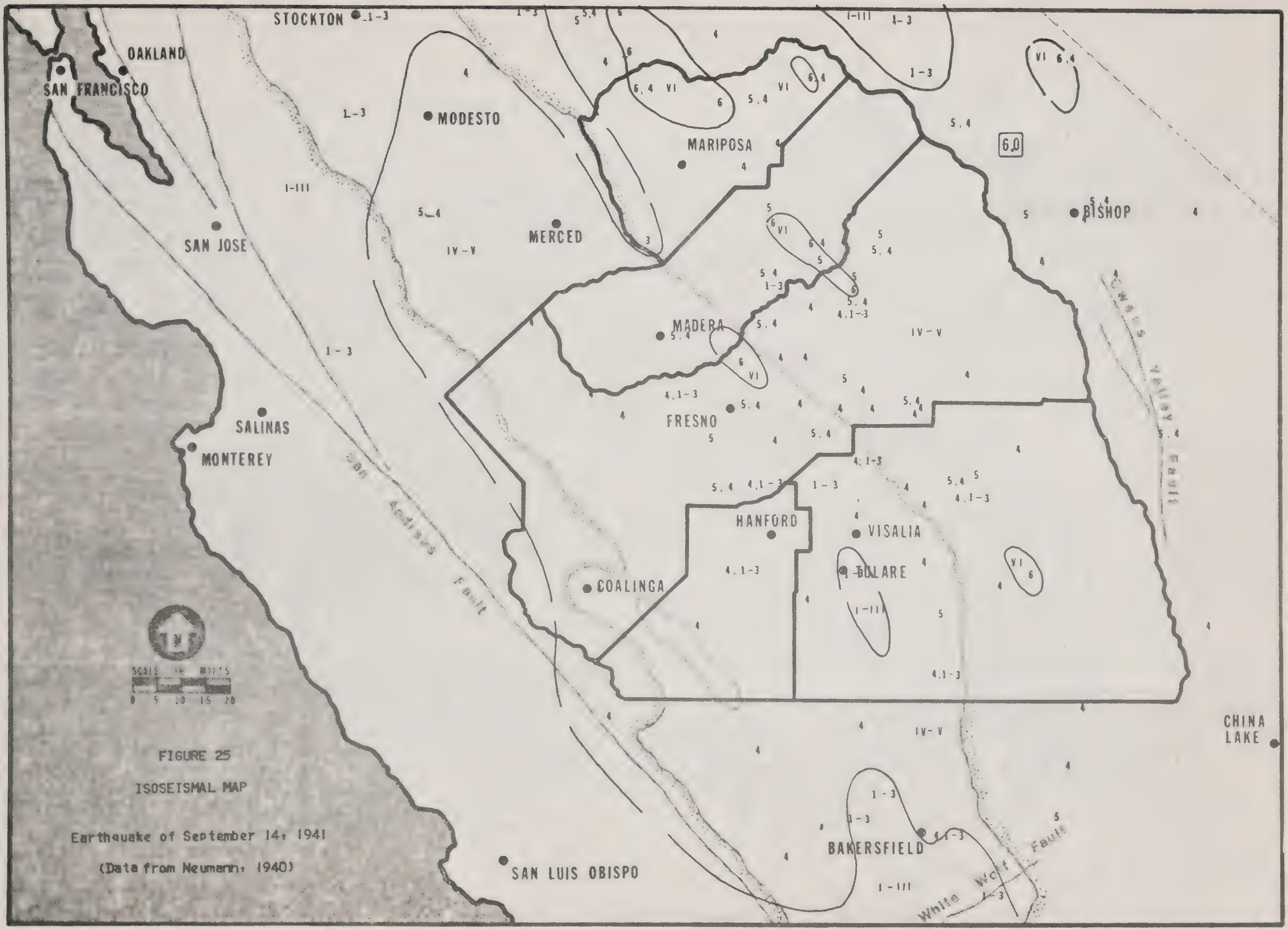


FIGURE 25

ISOSEISMAL MAP

Earthquake of September 14, 1941

(Data from Neumann, 1940)

GRAPHICS BY TULARE COUNTY PLANNING DEPARTMENT

FIGURE 26. ISOSEISMAL MAP (CALIFORNIA) Arvin-Tehachapi earthquake of July 21, 1952, from Neuman & Cloud, 1955

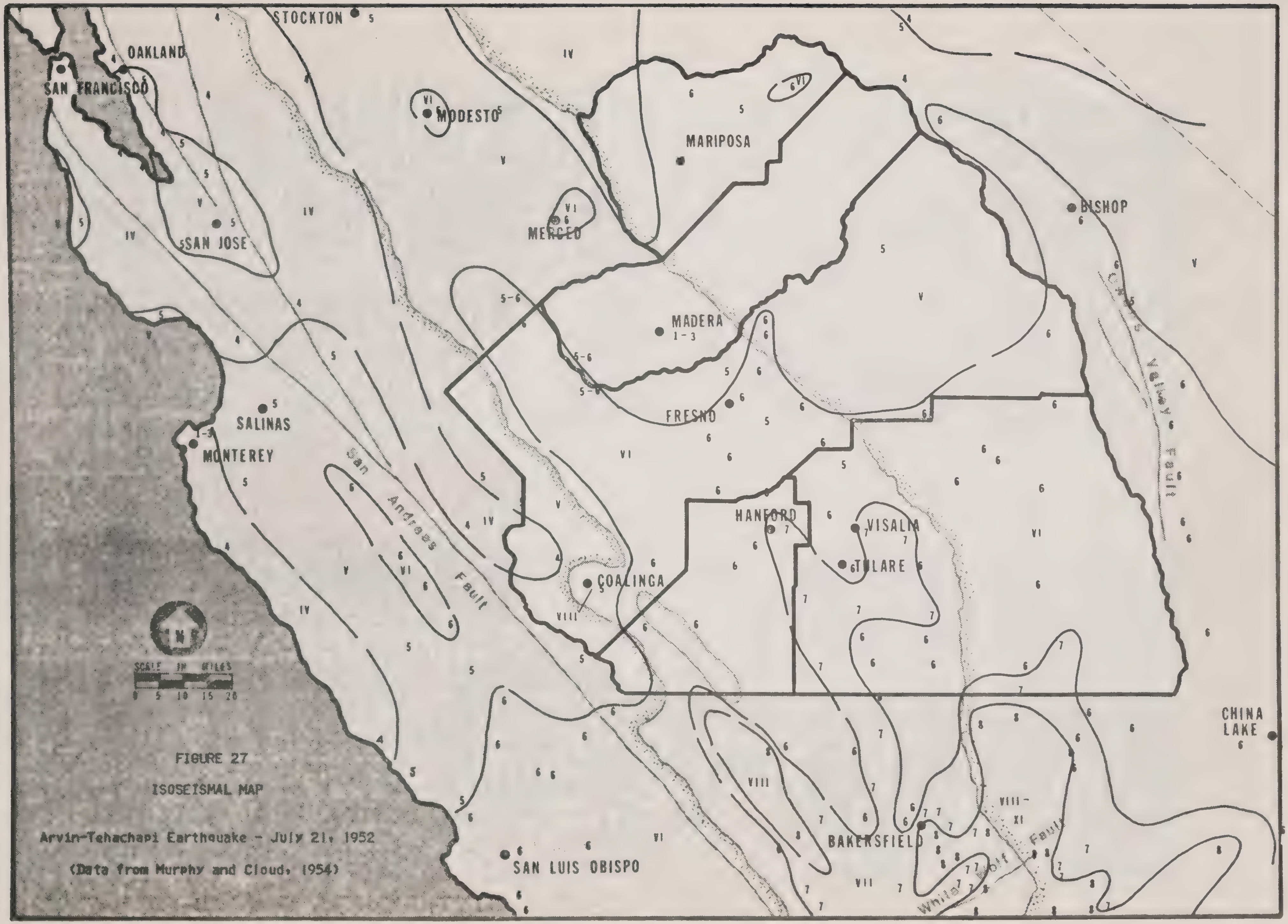


FIGURE 27

ISOSEISMAL MAP

Arvin-Tehachapi Earthquake - July 21, 1952

(Data from Murphy and Cloud, 1954)

GRAPHICS BY TULARE COUNTY PLANNING DEPARTMENT

4. Engineering Characteristics of Expected Earthquakes

a. Methodology

The derivation of the engineering characteristics of a particular earthquake at a particular site is normally a two-step process. These steps are the two considerations that have been discussed in describing the changes in earthquake intensity; that is, distance to the source of the earthquake and local conditions. Where the distance factor is treated as the travel path in deep bedrock, the effect of local conditions is the near-surface amplification of the waves as they travel upward through layered rocks. The mathematics and geometry of this calculation are shown in Figure 28. The distance problem is a relatively simple part of the calculation. However, near-surface amplification and the choice of type earthquakes are more complex problems to be discussed in detail in the next two sections.

b. Near-Surface Amplification

1. Physical Principles

The amplification of earthquake waves traveling through a media of differing physical characteristics (i.e. layered rocks) is based on two physical principles: conservation of energy, and the selective amplification of resonant frequencies.

The principle of conservation of energy applies to the transformation of the physical properties of a wave as it travels from the very fast, dense rocks at depth to the much slower, less dense rocks or soils at the surface. In this conversion, the energy of wave velocity is converted to energy of wave amplitude. The mathematical expression for this change as a wave travels from layer 1 to layer 2 is:

$$AR = \frac{D_2V_2}{D_1V_1}$$

where: AR = amplification ratio (layer 2 to layer 1),
D_1 = density of layer 1,
D_2 = density of layer 2,
V_1 = velocity of layer 1, and
V_2 = velocity of layer 2.

The above equation involves both velocity and density, but velocity is by far the most important. In the overall change from granite at depths greater than about 100 feet to a typical soil at the surface, the density will typically change from 2.7 to about 1.5; a ratio of less than 2:1. Velocity (shear-wave) on the other hand will typically change from about 11,000 ft/sec to less than 500 ft/sec; a ratio of more than 20:1, and 10 times the density change.

The selective amplification of resonant frequencies is more complex, but in simple terms, the rock layers act somewhat like a series of organ pipes that amplify waves of particular frequencies. The frequencies that are amplified are those that form a one-quarter-wavelength standing wave in the layer, and all higher modes. The dominant periods of a layer are thus:

$$T = \frac{4}{1}\frac{H}{V},\ \frac{4}{3}\frac{H}{V},\ \frac{4}{5}\frac{H}{V}\ \text{etc.}$$

where: T = dominant period,
H = layer thickness, and
V = layer velocity (shear wave).

For most sites, with many layers of varying thickness and a gradual increase of velocity with depth, selective amplification is secondary in importance to the more general amplification due to decreasing velocity and density. However, where there is a very pronounced velocity change at relatively shallow depth, as in the Mexico City area discussed in Introduction, the concentration of energy in a narrow frequency range can be very important for structures having a similar natural period of vibration.

In addition to the two principles considered above, damping can be important for sites with thick layered sequences. Waves traveling in fast, dense rocks such as granite are almost unaffected by damping, but unconsolidated materials such as soils, soft sands and shales can effectively damp earthquake waves if they are present in sufficient thickness. Overall, the effect is to cancel a part of the wave amplification of the slow, less dense rocks, because rocks with high amplification characteristics generally have high damping factors. For damping to be effective, however, thick layers are required. Thus, low velocity materials may be "good" or "bad." If, they are present as a relatively thin layer (15-100 feet), amplification may be very significant. However, if they are present as very thick layers (several thousands of feet), damping can be effective in reducing the amplification normally expected at sites underlain by low velocity rocks.

From the discussion above it is apparent that the most important physical characteristic of a site is the velocity or velocities of the layers underlying the site. Density is less important, and it can be estimated from velocity if the rock types are known. Damping is important for thick sections, and it too is closely related to velocity. Thus, if the velocity of the wave type of interest is known, the density and damping can generally be estimated to an acceptable degree of accuracy.

Earthquake shaking is the result of complex combinations of several types of vibrational waves. The primary components of earthquake waves are the so-called body waves that travel through the deeper parts of the earth's crust. Body waves include the primary (P-wave) or compressional waves and the secondary (S-wave) or shear waves. For waves traveling at depth, and refracted upward to the site (Figure 29), the P-waves, vibrating parallel to the propagation direction, dominate the vertical component of shaking. The S-waves arrive later and vibrate perpendicular to the direction of propagation; they make up the major part of the damage inducing, horizontal components of shaking. Thus, it is the shear waves that are of primary importance in the analysis of earthquake shaking.

2. Velocity Analysis

As developed in the previous section, it is shear-wave velocity that is the dominant physical parameter in the analysis of the near-surface amplification characteristics of a particular site. The problem is that the shear-wave velocity of rocks is difficult to measure, and is not normally available from studies for other purposes. P-wave velocity, however, is commonly measured at shallow depths to determine the excavation characteristics of rocks, and is the wave type recorded by oil companies in their seismic prospecting. Shear-wave studies have been conducted in other areas (e.g. Duke et al, 1971), and the ratios of S-wave to P-wave velocities developed from these studies can be used to estimate S-wave velocity from the measured P-wave velocity.

P-wave velocity data was contributed by the Standard Oil Company of California (see Acknowledgements), and consists of three types of data distributed generally within the Five-County area as listed below:

1. Deep well velocity surveys with control points at 500 to 1000 foot intervals, or continuous sonic logs of deep wells with or without check shots at similar intervals, located primarily in the areas of greater oil potential in the western and southern parts of the Valley and along the western foothills.

2. Shallow velocity (0-100 feet) from reflection seismograph data, primarily multiple up-hole shots or first-break refraction analysis, available primarily for the central and western parts of the Valley.

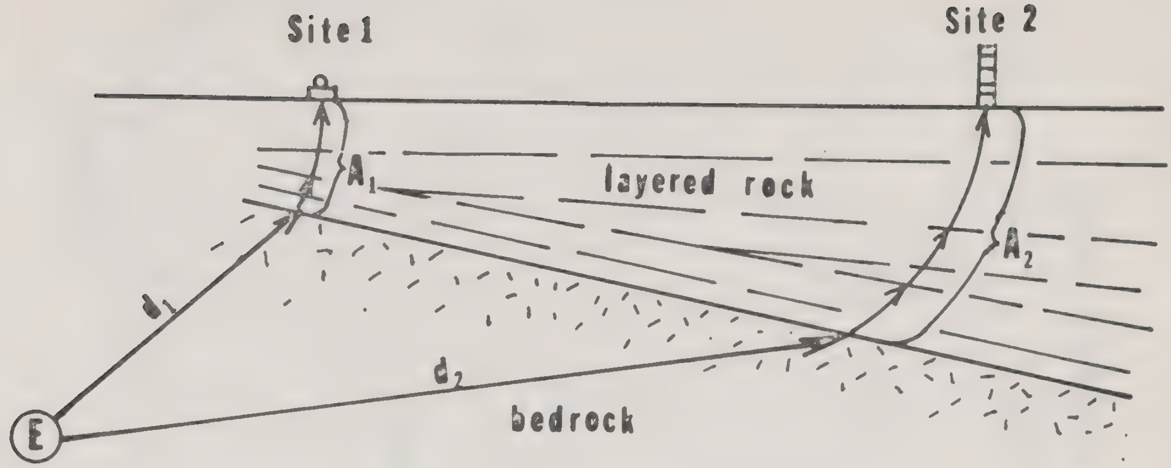
3. Deep up-hole (0-500 feet) velocity surveys available from more recent work in the western part of the Valley, primarily in the vicinity of Interstate 5.

Each of the above types of data tend to supplement each other. The deep well surveys are limited to that part of the well below surface casing which in the Five-County area is often below 1,000 ft. For the more recent surveys, a deep uphole may be available down to 400 or 500 feet. The shallow velocity data is obtained for control of the so called "depth of weathering," and is limited to intervals down to about 100 feet. The more recent up-hole cable data helps to fill the gap between the shallow data (down to 100 feet) and the deep well data (below 1000 feet), but this information is limited. Thus, to compile complete velocity data for a particular site, some input from each of the three source types is desirable.

Another aspect of the data distribution is that it is not available, or is old and of rather poor quality, for areas generally east of Highway 99. For this reason, and to supplement and check the data available at the surveyed locations, the three types of velocity data have been analyzed by a number of different methods. These include plotting velocity against depth, and the plotting and [illegible]ring of the areal distribution of [illegible]ty in the three shallowest veloc[illegible]yers. The principal conclusions [illegible]ved from this analysis are as follows:

1. Shallow P-wave velocity averages about 2000 ft/sec and is not less than 1000 ft/sec at any of the locations surveyed (Figure 30).

2. The base of the shallow velocity layer compares well with the top of the water table, but a precise comparison cannot be made because of the complex fluctuations of the water table in recent years.



The spectrum, S_{V1}, of the earthquake, E, recorded at site 1, at distance d, from the source of the earthquake is:

$$S_{V1} = \frac{E\ A_1}{d_1}$$

where A is the near-surface amplification of the bedrock motion, damping in bedrock is negligible, and spreading is cylindrical. Likewise, the spectrum at site 2 is:

$$S_{V2} = \frac{E\ A_2}{d_2}$$

Therefore:

$$S_{V2} = S_{V1}\ \frac{d_1}{d_2}\ \frac{A_1}{A_2}$$

Where S_{V1}, S_{V2}, A_1, and A_2 are complex functions of frequency.

Figure 28. Geometry and mathematics of computation of the engineering characteristics of an earthquake.

SOURCE: ENVICOM

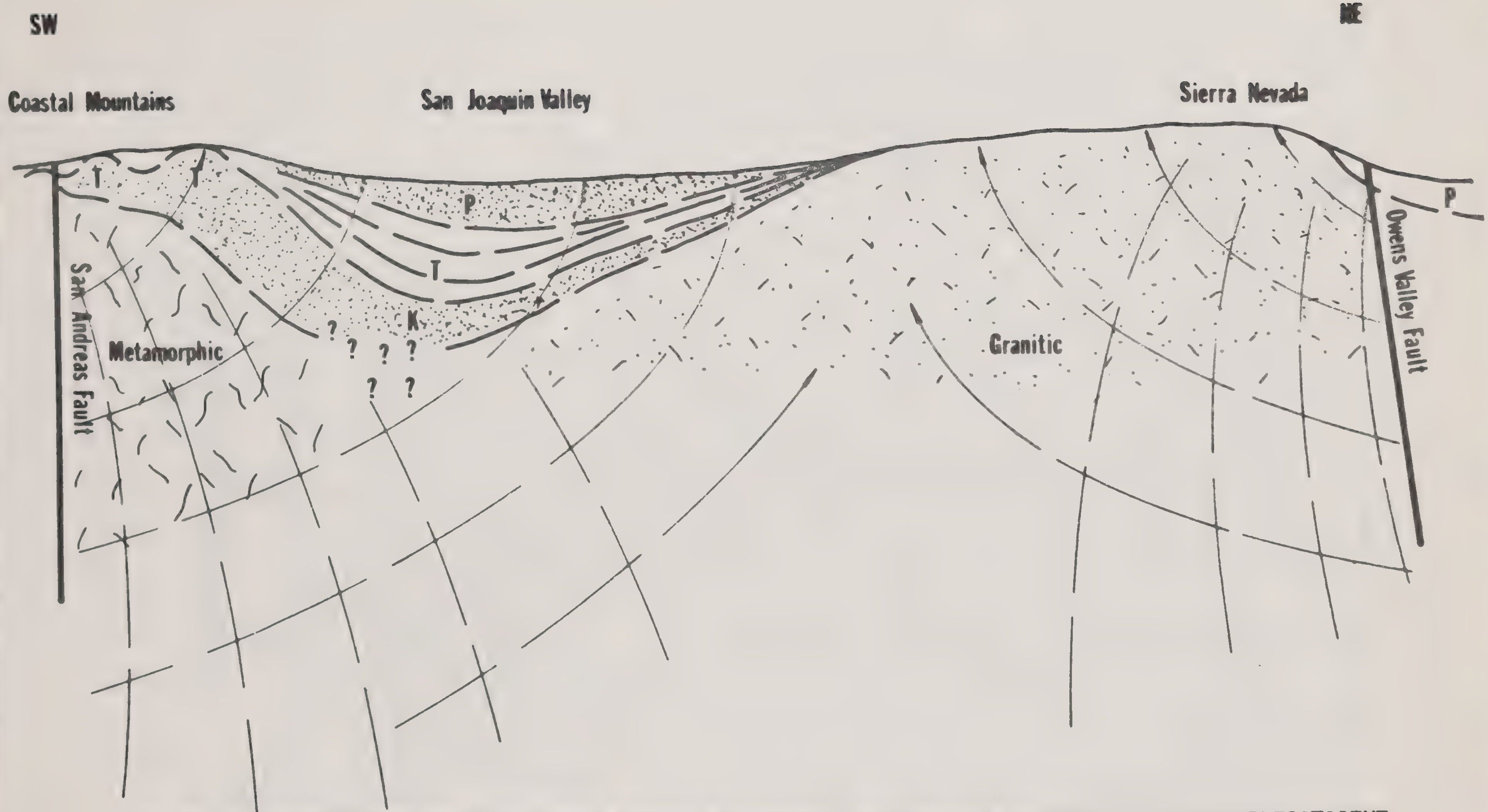


FIGURE 29 GENERALIZED GEOLOGIC CROSS SECTION WITH WAVE PROPAGATION PATTERN. P = PLIO-PLEISTOCENE ROCKS; T = MIDDLE AND LOWER TERTIARY ROCKS; AND K = UPPER CRETACEOUS ROCKS.

GRAPHICS BY TULARE COUNTY PLANNING DEPARTMENT SOURCE: ENVICOM

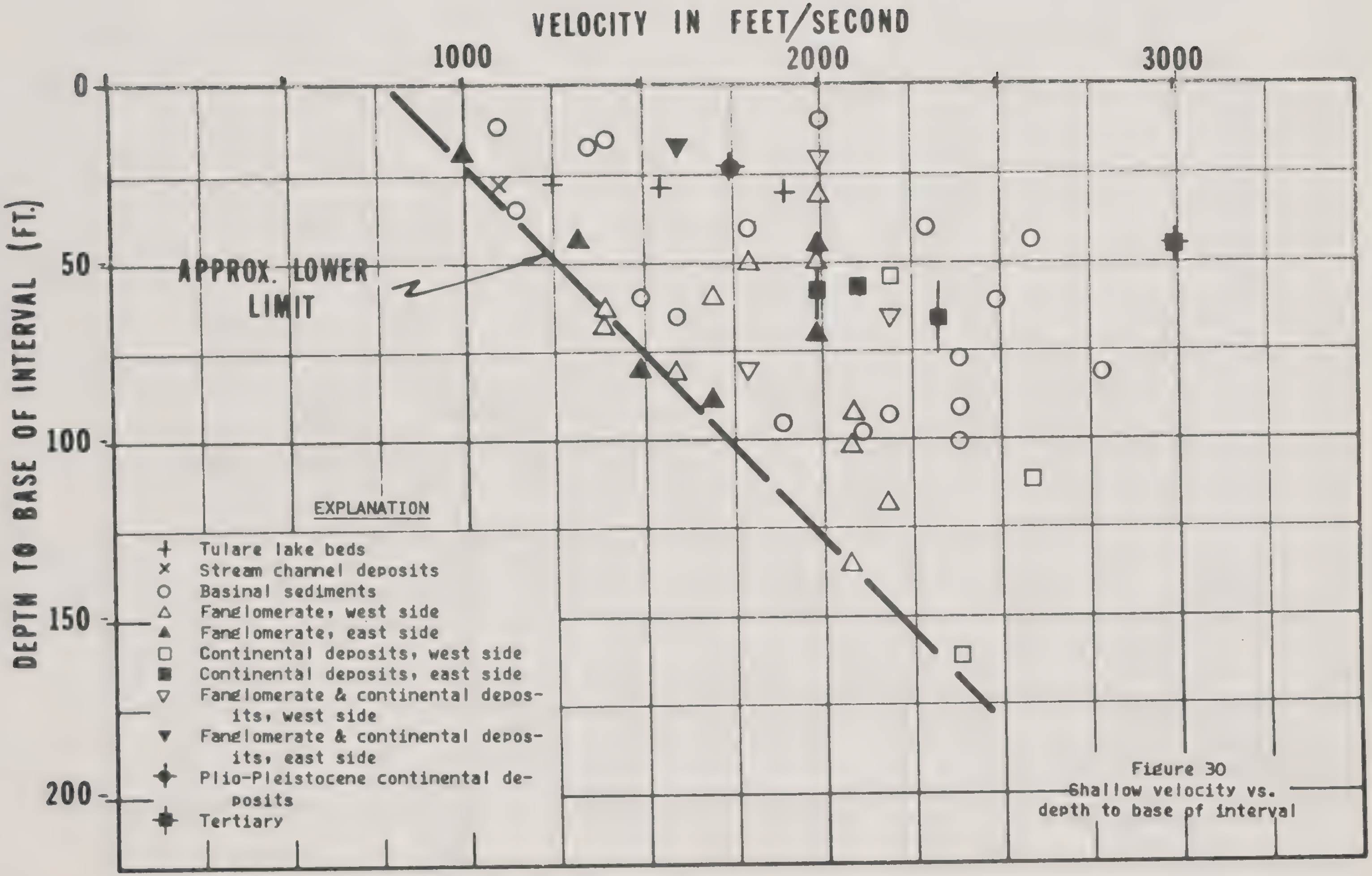


Figure 30
Shallow velocity vs. depth to base of interval

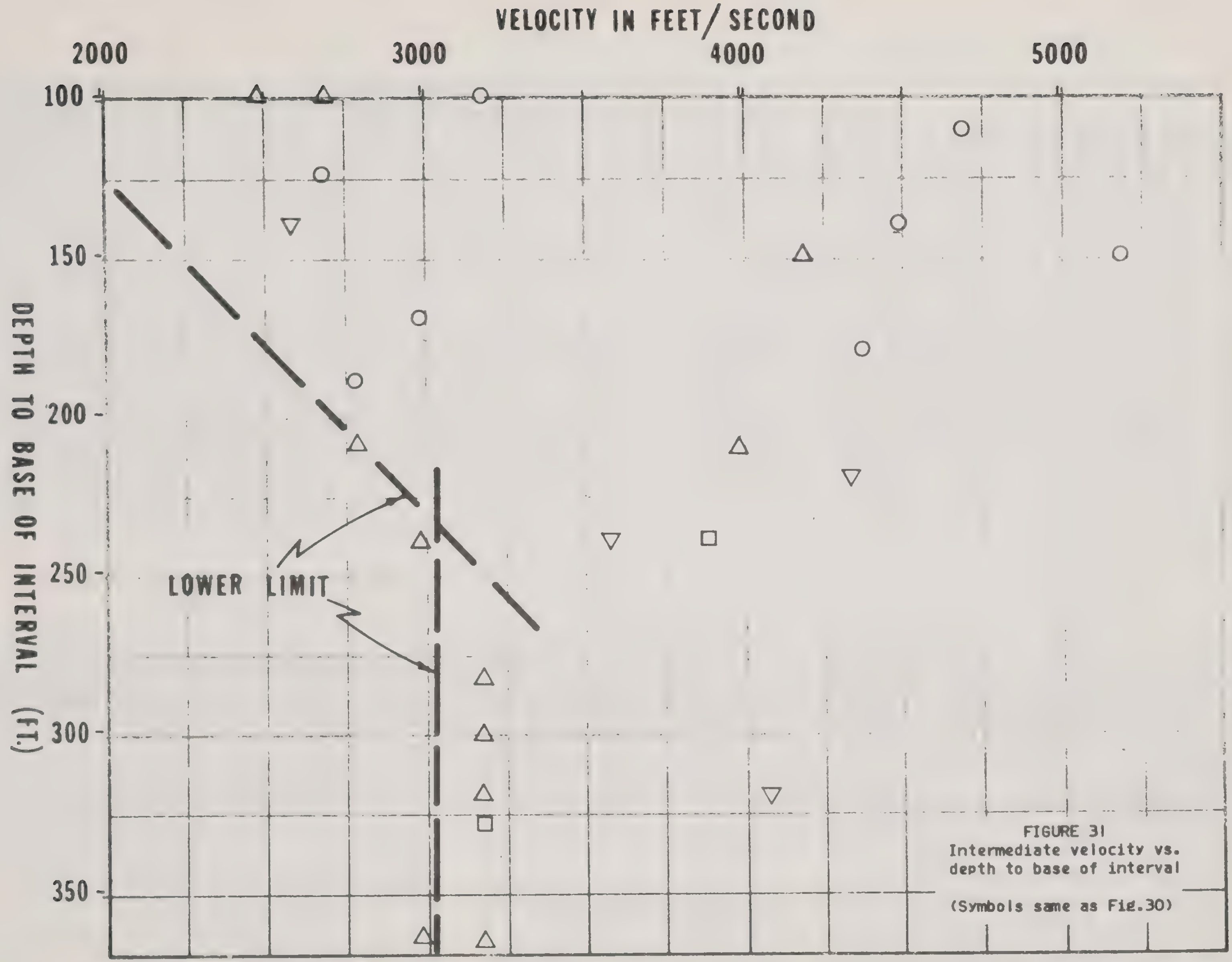


FIGURE 31
Intermediate velocity vs. depth to base of interval

(Symbols same as Fig.30)

GRAPHICS BY TULARE COUNTY PLANNING DEPARTMENT

SOURCE: ENVICOM

3. An intermediate layer with velocities of 2500 to 4500 ft/sec (Figure 31) is present on the west side of the Valley.

4. The intermediate velocity layer appears to be associated with the zone of partial water saturation between the perched layer and the deep water levels. Isolated occurrences of an intermediate layer on the east side appear to be related to recent draw-down of the unconfined aquifer.

5. There is no consistent relationship between shallow velocity and rock group as mapped on the State Geologic Map (Figure 30). However, the fanglomerates (Qf on map) are generally slowest in relation to depth, and the continental deposits (Qc on map) are the faster. The basinal deposits (Qb on map) vary considerably.

These relationships and contour maps of the shallow velocity layers have been used to interpret P-wave velocity at sites where this data is not available from an actual survey at the site.

3. <u>Multi-Layer Models</u>

Multi-layer models have been developed for 14 sites within the Five-County area. (Table 9) The sites were chosen to test near-surface amplification for a wide variety of conditions within the area, and specific locations are shown on Plate I. Factors considered in the choice of sites include the location of geologic and velocity control, location of population centers, and extremes of velocity and geologic conditions requiring evaluation. Specific geologic and velocity data used in developing the modules is shown on Table 10 and the model data sheets on the pages that follow. Shear-wave velocity has been interpreted from P-wave velocity using relationships developed from studies of data recorded during the San Fernando earthquake of 1971 (Duke et al, 1971) with a smoothed transition across the water table. The latter affects the P-wave velocity, but has only a minor effect on the shear-wave velocity. The density is estimated from the P-wave velocity, and, although approximate, is considered adequate considering the lesser influence of density as comparison to the velocity. Detailed density data is available for several sites investigated by the U.S. Geological Survey (Meade, 1967) in the area of land subsidence on the west side of the Valley. The very low densities reported even at depths of 1500 to 2000 feet were tested at Site 7 (Cantua Creek).

The near-surface amplification characteristics for each of the sites were evaluated by computer using programs based on the principles discussed previously. Processing and plotting was accomplished by Mr. J. A. Johnson under the supervision of Prof. C. Martin Duke of U.C.L.A. All input data was checked by Mr. Johnson who has had considerable experience in the utilization and evaluation of these programs using recorded data from the recent San Fernando and Managua earthquakes. The plots of the amplification spectra (Figures 32 thru 46) for the 14 sites are included on the pages following the site data (Tables 11 thru 24). These spectra show the amplification factor plotted as a function of period. Generalized amplification levels for short and long periods to be used in the microzonation are also shown on the plots.

c. <u>Type Earthquakes</u>

The primary influence on the future seismicity of the San Joaquin Valley and Coast Ranges is the expected magnitude 8.3 to 8.5 earthquake on the San Andreas fault. Smaller earthquakes which occur at fairly regular intervals along the active segment of this major fault are not considered because shaking will be less intense than that expected as a result of the larger earthquake. If structures are designed to resist the shaking of the larger earthquake, they should easily resist that of the smaller earthquakes.

The strong motion of an earthquake of magnitude 8.3 to 8.5 has not been recorded. To fill this gap, the motion has been simulated by Jennings, Housner and Tsai (1968) and by Seed and Idriss (1969) using the records of the larger earthquakes (e.g. Taft record of the Arvin-Tehachapi earthquake) and theory regarding the variation in earthquake characteristics with increasing magnitude. The results of the two studies are very similar. The response spectra of the two simulated motions agree well up to a period of about 2.0 seconds, but for the longer periods the motion proposed by Seed and Idriss has substantially lower response. The motion proposed by Jennings, Housner and Tsai has been used in this study because it assumes a site on firm alluvium which better fits the more populated parts of the area. One component of this motion is shown as Figure 47, and its response spectrum is shown as Figure 48.

The smaller earthquakes from the Owens Valley fault group are within the range of earthquakes that have been recorded and studied. Data on the characteristics of earthquakes of this magnitude (6.0-7.0) are not a significant problem.

TABLE 9
SITES INVESTIGATED FOR NEAR-SURFACE
AMPLIFICATION CHARACTERISTICS

Site Number	General Location	Designation and Nearest Town or City
1.	Sec. 20, T23S, R26E	South-central Tulare County near Earlimart
2.	Sec. 30, T23S, R22E	Near Trico gas field, west of Alpaugh
3.	T23S, R20E	East of Kettleman Hills, south-east of Kettleman City
4.	Sec. 2, T21S, R16E	Guijarral Hills, east of Coalinga
5.	Sec. 8, T19S, R22E	Hanford
6.	SW 1/4, T18S, R25E	Visalia
7.	Sec. 14, T17S, R15E	Cantua Creek, west of Five Points
8.	Sec. 14, T15S, R17E	Raisin City
9.	T13S, R20E	Fresno
10.	Sec. 29, T14S, R13E	Cheney Ranch, Southwest of Mendota
11.	W 1/2, T13S, R16E	Gill Ranch, northeast of Mendota
12.	N 1/2, T13S, R21E	Clovis
13.	Sec. 28, T11S, R12E	North-central area, south of Dos Palos
14.	T21S, R15E	Jacalitos oil field, south of Coalinga

TABLE 10
SOURCES OF DATA FOR MULTI-LAYER MODELS

Velocity and Density:

1. Shallow uphole or refraction data from seismic survey.

2. Deep uphole from seismic survey.

3. Regional analysis of shallow and intermediate velocity data.

4. Well survey, interval velocity.

5. Well survey, with sonic log.

6. Estimated from nearest well surveys using geologic formation and depth.

NOTE: The suffix "A" denotes that the data is based on a nearby survey. This data is considered to be intermediate in reliability between site data (1, 2, 4 and 5) and that from regional analysis (3 and 6).

Geological:

7. Geologic Map of California

8. Oil field data (Calif. Div. of Oil & Gas, 1961)

9. Correlation Section, San Joaquin Valley, Kingsburg to Tejon Hills (Amer. Assoc. Pet. Geol., 1969)

10. Correlation Section, Central San Joaquin Valley, Riverdale through Tejon Ranch (Amer. Assoc. Pet. Geol., 1958A)

11. Correlation Section, Westside San Joaquin Valley, Coalinga to Midway Sunset and across San Andreas Fault to Southeast Cuyama Valley (Amer. Assoc. Pet. Geol., 1959).

12. Correlation Section, Central San Joaquin Valley, San Andreas Fault to Sierra Nevada Foothills. (Amer. Assoc. Pet. Geol., 1957).

13. Correlation Section, Central San Joaquin Valley, Rio Vista through Riverdale (Amer. Assoc. Pet. Geol., 1958B).

(Continued)

TABLE 10 Cont.

General Geological:

14. Compaction of sediments underlying areas of land subsidence in Central California (Meade, 1968)

15. Madera area investigation (Calif. Dept. of Water Resources, 1966)

16. Physical and hydrologic properties of water-bearing deposits in subsiding areas in Central California (Johnson et. al., 1968)

17. Geology of the late Tertiary and Quaternary water-bearing deposits of the southern part of the San Joaquin Valley, California (Croft, 1969)

18. Geology, hydrology and water quality in the Fresno area, California (Page and Le Blanc, 1969)

19. Geology, hydrology and quality of water in the Madera area, San Joaquin Valley, California (Mitten et. al., 1970)

20. Groundwater conditions and potential pumping resources above the Corcoran Clay, San Luis Unit, Central Valley Project, California (U. S. Bureau of Reclamation, 1965)

21. Geology and construction materials data, earthwork and structures, Kettleman City to Avenal Gap, mile 174.8 to 187.1 (Calif. Dept. of Water Resources, 1965)

SITE CHARACTERISTICS

TABLE: 11 SITE NO: 1

AREA: South-Central Tulare Co. LOCATION: Sec. 20, T23N,R26E

Geologic Conditions					Physical Properties			
Depth to Top of Interval (feet)	Thickness of Interval (feet)	Formation, Age, Lithology, etc.	Water Table	Source	P-Velocity (ft./sec.)	Source	S-Velocity (ft./sec.)	Density (lbs/cu ft)
0	75	Qc	75	7	1600	1A	720	100
75	115		190	9	2500	3	1125	115
190	110	Kern River		9	6200	1A	2900	140
300	1360	(L.Pleist. & Plio.)		9	7000	5	3500	144
1660	640			9	7500	5	3750	144
2300	2200	(U. & L. Miocene)		9	8500	5	4250	144
4500	100	Granite basement		9	14,000	5	9100	153
4600	10,000			9	19,000	5	12,350	170

SITE CHARACTERISTICS

TABLE: 12 | SITE NO: 2

AREA: Near Trico gas field | LOCATION: Sec.30,T23S,R22E

Geologic Conditions					Physical Properties			
Depth to Top of Interval (feet)	Thickness of Interval (feet)	Formation, Age, Lithology, etc.	Water Table	Source	P-Velocity (ft./sec.)	Source	S-Velocity (ft./sec.)	Density (lbs/cu ft)
0	5	Ql	5	7	1500	1	675	106
5	50	(Tulare Lake Sediments)		7	5600	1	1300	134
55	1345	Kern River/Tulare		4	5200	4,5	2450	122
1400	500	(Pleist. & U.Plio.)		4	5400	4,5	2700	122
1900	600			4	5900	4,5	2950	125
2500	200			4	6900	4,5	3450	131
2750	550	San Joaquin		4	6500	4,5	3250	128
3250	200	& Etchegoin		4	8500	4,5	4250	137
3450	300	(Pliocene)		4	6600	4,5	3300	128
3750	4250			4	7000	6	3700	131
8000	4000			4	8000	6	4800	144
12,000	1000	(Miocene)		4	9500	4A	5700	144
13,000	1200	Panoche: Brown Mtn. Ss.		4	15,000	4A	9000	156
14,200	500	Panoche: Ragged Valley Sh.		4	14,500	6	8700	156
14,700	500	Panoche: Joaquin Ridge Ss.		4	16,000	6	9600	160
15,200	100	Granitic (?) basement		4	15,500	6	10,100	162
15,300	10,000			4	19,000	6	12,350	170

SITE CHARACTERISTICS

TABLE: 13

SITE NO: 3

AREA: East of Kettleman Hills

LOCATION: T23S, R20E

Geologic Conditions					Physical Properties			
Depth to Top of Interval (feet)	Thickness of Interval (feet)	Formation, Age, Lithology, etc.	Water Table	Source	P-Velocity (ft./sec.)	Source	S-Velocity (ft./sec.)	Density (lbs/cu ft)
0	5	Ql & Qb		7	1250		560	100
5	25	Kern River/Tulare		12	5000		1000	125
30	1400	(Plio. - Pleist.)		12	5600		2500	131
1430	1820	? ?		12	6300		3150	134
3250	1350	San Joaquin &		12	7800		3900	137
4600	900	Etchegoin		12	8400		4200	137
5500	1000	(Pliocene)		12	9200		5060	140
6500	1000			12	10,000		5500	144
7500	500	U.Mio. Santa Margarita Ss.		12	9500		5225	140
8000	1800	U.Mio. McClure Sh.		12	9800		5390	144
9800	1200	M.&L.Mio. Temblor		12	10,500		6300	147
11,000	1200			12	14,500		8700	159
12,200	800	Olig. + U. Eo. Sh.		12	12,000		7200	150
13,000	300	Eo. Gatchell Ss.		12	15,000		9000	162
13,300	700	Eo. Cantua Sh.		12	13,500		8100	156
14,000	900	U. Cret. Panoche Moreno Sh.		12	14,000		8400	159
14,900	1600	U. Cret. Panoche Brown Mtn. Ss.		12	15,500		9300	162
16,500	800	U. Cret. Panoche Ragged Valley Ss.		12	14,500		8700	159
17,300	700	U. Cret. Panoche Joaquin Ridge Ss.		12	16,000		9600	165
18,000	100	Granitic (?) basement		12	17,000		11,050	170
18,100	10,000			12	18,000		11,200	170

SITE CHARACTERISTICS

TABLE: 14

SITE NO: 4

AREA: Guijarral Hills (east of Coalinga)

LOCATION: Sec.2, T21S, R16E

Geologic Conditions					Physical Properties			
Depth to Top of Interval (feet)	Thickness of Interval (feet)	Formation, Age, Lithology, etc.	Water Table	Source	P-Velocity (ft./sec.)	Source	S-Velocity (ft./sec.)	Density (lbs/cu ft)
0	25	Q-P		7	1800	1	810	109
25	280	Tulare/Kern River		11	3600	3	1620	125
300	600	(Plio. - Pleist.)		11	6600	4	3170	131
900	1000	San Joaquin		11	7200	4	3600	131
1900	1000	(Plio.)		11	7800	4	3900	134
2900	1000	Etchegoin (Plio.)		11	8600	4	4300	140
3900	3100			11	9300	4	4930	144
7000	1000	(U. Mio.)		11	12,300	4	6700	153
8000	600	(M. Mio.)		11	14,000	4	7700	159
8600	2600	Eo. + Olig.		11	15,000	6	9000	162
11,200	700	U. Cret. Panoche Moreno Sh.		11	14,500	6	8700	165
11,900	1800	U. Cret. Panoche Brown Mtn. Ss.		11	16,500	6	9900	165
13,700	700	U. Cret. Panoche Ragged Valley Sh.		11	15,000	6	9000	165
14,400	800	U. Cret. Panoche Joaquin Ridge Ss.		11	16,500	6	9900	165
15,200	100	Granitic (?) basement		11	16,000	6	10,400	165
15,300	10,000			11	20,000	6	13,000	172

SITE CHARACTERISTICS

TABLE: 15

SITE NO: 5

AREA: Hanford

LOCATION: Sec.8, T19S, R22E

Geologic Conditions					Physical Properties			
Depth to Top of Interval (feet)	Thickness of Interval (feet)	Formation, Age, Lithology, etc.	Water Table	Source	P-Velocity (ft./sec.)	Source	S-Velocity (ft./sec.)	Density (lbs/cu ft)
0	40	Qf		7	1300	1	590	100
40	30	Tulare/Kern River		9,10	3000	2A	1350	112
70	930	(Plio-Pleist.)		9,10	6000	2A	2900	125
1000	950			9,10	6800	4	3400	131
1950	1000			9,10	7300	4	3650	134
2950	1000	(Pliocene)		9,10	8350	4	4200	137
3950	550			9,10	8700	4	4350	140
4500	200	Santa Margarita (U. Mio.)		9,10	7400	4	3700	134
4700	2600	(M. & L. Mio.)		9,10	8900	4	4900	140
7300	1800	(Eo. + U. Cret.)		9,10	9600	4	5300	144
9100	3900	(U. Cret.)		9,10	10,500	6	6300	147
13,000	100	Granite basement		9,10	14,000	4A	9100	149
13,100	10,000			9,10	19,000	4A	12,350	170

SITE CHARACTERISTICS

TABLE: 16 SITE NO: 6

AREA: Visalia LOCATION: SW1/4,T18S,R25E

Geologic Conditions					Physical Properties			
Depth to Top of Interval (feet)	Thickness of Interval (feet)	Formation, Age, Lithology, etc.	Water Table	Source	P-Velocity (ft./sec.)	Source	S-Velocity (ft./sec.)	Density (lbs/cu ft)
0	25	Qf		7	1400	1	630	103
25	75	Kern River		9A	6000	1	1300	110
50	200	(Pleist.+Plio.)		9A	6000	5A	2700	128
300	1300			9A	7000	5A	3290	128
1600	200	(U.Mio.)Santa Margarita		9A	6500	6	3250	128
1800	800	(M.&L.Mio.)		9A	8000		4000	137
2600	100	Granite basement		9A	14,000		9100	159
2700	10,000			9A	19,000		12,300	170

SITE CHARACTERISTICS

TABLE: 17 SITE NO: 7

AREA: Cantua Creek LOCATION: Sec. 14, T17S, R15E

Geologic Conditions					Physical Properties			
Depth to Top of Interval (feet)	Thickness of Interval (feet)	Formation, Age, Lithology, etc.	Water Table	Source	P-Velocity (ft./sec.)	Source	S-Velocity (ft./sec.)	Density (lbs/cu ft)
0	48	Qf		7	2000	3	900	112
48	192	Kern River		9,12	3000	3	1350	119
240	760	(Plio. - Pleist.)		9,12	6000	3	2500	128
1000	1200	San Joaquin		9,12	6700	6	3000	131
2200	1500	Etchegoin		9,12	7700	6	3850	134
3700	1000	U. Mio. Santa Marg. McLure		9,12	8700	6	4350	137
4700	1800	Temblor		9,12	9200	6	5050	140
6500	1000	Kregenhagen		9,12	10,200	6	5600	147
7500	700	Loescher & Cat.		9,12	10,500	6	5800	147
8300	1500	Lower Hondo		9,12	10,700	6	5900	147
9800	1200	Cantua Ss.		9,12	8800	6	5250	140
11,000	600	Moreno Sh.		9,12	9600	6	5760	144
11,600	1200	U. Cret. Panoche Brown Mtn.		9,12	11,200	6	6720	150
12,800	800	Ragged Valley		9,12	12,500	6	7500	156
13,600	800	Joaquin Ridge		9,12	14,000	6	8400	162
14,400	100	Granite (?) basement		9,12	15,500	6	10,000	162
14,500	10,000			9,12	19,000	6	12,350	170

SITE CHARACTERISTICS

TABLE: 18

SITE NO: 8

AREA: Raisin City

LOCATION: Sec. 14, T15S, R17E

Geologic Conditions					Physical Properties			
Depth to Top of Interval (feet)	Thickness of Interval (feet)	Formation, Age, Lithology, etc.	Water Table	Source	P-Velocity (ft./sec.)	Source	S-Velocity (ft./sec.)	Density (lbs/cu ft)
0	90	Qb		7	2000	1A	900	112
90	50	Kern River/Tulare		8,13	2700	1A	1215	115
140	860	(Plio. - Pleist.)		8,13	5800	2A	2600	134
1000	1000			8,13	6800	4A	3400	137
2000	1000			8,13	7500	4A	3750	140
3000	900			8,13	8400	4A	4200	144
3900	600			8,13	7200	4A	3600	137
4500	600	(U.Mio.) Santa Margarita		8,13	7200	4A	3600	137
5100	1400	(L + M. Mio.) Zilch		8,13	8800	4A	4850	140
6500	450	(Olig. + Eo.)		8,13	8400	4A	4600	137
6950	650	U. Cret. Moreno Sh.		8,13	9000	4A	4950	140
7600	4000	U. Cret. Panoche Ss.		8,13	10,500	4A	5800	147
11,600	100	Granitic basement		8,13	14,000	4A	9100	159
11,700	10,000			8,13	19,000	4A		

SITE CHARACTERISTICS

TABLE: 19 SITE NO: 9

AREA: Fresno LOCATION: T13S, R20E

Geologic Conditions					Physical Properties			
Depth to Top of Interval (feet)	Thickness of Interval (feet)	Formation, Age, Lithology, etc.	Water Table	Source	P-Velocity (ft./sec.)	Source	S-Velocity (ft./sec.)	Density (lbs/cu ft)
0	70	Qf & Qc		7	1600	1	720	106
70	100	Tulare/Kern River		12	6000	1	1200	112
170	330	(Plio. - Pleistocene)		12	6000	6	2700	125
500	1000			12	6500	6	3120	131
1500	1000			12	7000	6	3500	131
2500	1500	Mio.-U.Cret. Zilch		12	7500	6	3750	134
4000	100	Granitic basement		12	14,000	6	9100	159
4100	10,000			12	19,000	6	12,350	170

SITE CHARACTERISTICS

TABLE: 20

SITE NO: 10

AREA: Cheney Ranch

LOCATION: Sec. 29, T14S, R13E

Geologic Conditions					Physical Properties			
Depth to Top of Interval (feet)	Thickness of Interval (feet)	Formation, Age, Lithology, etc.	Water Table	Source	P-Velocity (ft./sec.)	Source	S-Velocity (ft./sec.)	Density (lbs/cu ft)
0	135	Qf		7	2200	2A	990	112
135	205			8	3200	2A	1440	119
340	460	Pleistocene, Pliocene		8	5800	2A	2600	128
800	700	and Miocene		8	6800	6	3250	131
1500	1000			8	7800	6	3900	134
2500	1000			8	8500	6	4250	137
3500	1000	(Olig.+Eo.) Kreyenhagen		8	8000	6	4000	134
4500	1250	Eo. + Paleo.)		8	8500	6	4250	137
5750	1400	(U.Cret.) Moreno Sh.		8	9000	6	4900	140
7150	1500	(U.Cret.) Panoche Brown Mtn. Ss.		8	10,500	6	5700	147
8650	1250	Ragged V. Sh.		8	10,000	6	6000	144
9900	1200	Joaquin R. Ss.		8	11,000	6	6600	150
11,000	100	Basement		8	12,500	6	7500	153
11,100	10,000	(Franciscan ?)		8	19,000	6	12,300	170

SITE CHARACTERISTICS

TABLE: 21 SITE NO: 11

AREA: Gill Ranch LOCATION: West half, T13S, R16E

Geologic Conditions					Physical Properties			
Depth to Top of Interval (feet)	Thickness of Interval (feet)	Formation, Age, Lithology, etc.	Water Table	Source	P-Velocity (ft./sec.)	Source	S-Velocity (ft./sec.)	Density (lbs/cu ft)
0	30	Qsc		7	1100	1	495	9
30	20	Kern River/Tulare		8,13	1500	1	675	106
50	250	(Plio. - Pleist.)		8,13	5800	6	2610	134
300	1200			8,13	6200	6	2975	134
1500	1400			8,13	6800	6	3400	134
2900	500	(U.Mio.) Santa Margarita		8,13	7200	6	3600	137
3400	900	(L. & M. Mio.) Zilch		8,13	8600	6	4300	140
4300	350	(Olig. + Eo.) Krey. & Dom.		8	8200	6	4100	137
4650	450	Moreno Sh.		8	8700	6	4350	140
5100	700	U. Cret. Ragged Valley Ss.		8	9500	6	5225	144
5800	3350	Panoche		8	10,000	6	5500	144
9150	100	Granitic basement		8	14,000	6	9100	159
9250	10,000			8	19,000	6	12,350	168

SITE CHARACTERISTICS

TABLE: 22 SITE NO: 12

AREA: Clovis LOCATION: North half,T13S, R21E

Geologic Conditions / Physical Properties

Depth to Top of Interval (feet)	Thickness of Interval (feet)	Formation, Age, Lithology, etc.	Water Table	Source	P-Velocity (ft./sec.)	Source	S-Velocity (ft./sec.)	Density (lbs/cu ft)
0	30	Qf		7	1600	1	720	106
30	70	Tulare/Kern River		12	6000	1	1200	112
100	400	(Plio. - Pleistocene)		12	6000	6	2700	125
500	1000			12	6500	6	3120	131
1500	500			12	7000	6	3500	131
2000	100	Granitic basement		12	14,000	6	9100	159
2100	10,000			12	19,000	6	12,350	170

SITE CHARACTERISTICS

TABLE: 23 SITE NO: 13

AREA: North Central LOCATION: Sec.28, T11S, R12E

Geologic Conditions					Physical Properties			
Depth to Top of Interval (feet)	Thickness of Interval (feet)	Formation, Age, Lithology, etc.	Water Table	Source	P-Velocity (ft./sec.)	Source	S-Velocity (ft./sec.)	Density (lbs/cu ft)
0	10	Qb		7	1100	1	490	97
10	90			13	5700	4	800	106
100	210	Tulare/Kern River		13	5700	4	2565	134
310	1090	(Plio.-Pleistocene)		13	6400	4	2880	137
1400	1800			13	7600	4	3800	140
3200	400	(U.Mio.) Santa Margarita		13	7200	4	3600	134
3600	1400	(Mio. & Olig. & Eo.)		13	8500	4	4250	140
5000	2000			13	9200	4	5060	144
7000	3000			13	10,000	4	5500	147
10,000	400	(U. Cret.)		13	11,000	4	6600	150
10,400	2600	? ?		13	13,500	4	8100	156
13,000	100	Granitic basement		13	14,000	6	9100	159
13,100	10,000			13	10,000	6	11,200	170

SITE CHARACTERISTICS

TABLE: 24

SITE NO: 14

AREA: Jacalitos Oil Field

LOCATION: T21S, R15E

Geologic Conditions					Physical Properties			
Depth to Top of Interval (feet)	Thickness of Interval (feet)	Formation, Age, Lithology, etc.	Water Table	Source	P-Velocity (ft./sec.)	Source	S-Velocity (ft./sec.)	Density (lbs/cu ft)
0	10	(surface weathering)		8,12	3000	6	1350	119
10	30	Etchegoin/Jacalitos		8,12	7000	6	3150	131
40	1960			8,12	8600	4	4120	137
2000	1000			8,12	9400	4	4700	144
3000	200	(U. Mio.) Reef Ridge Sh.		8,12	9000	4	4500	144
3200	200	McLure Sh.		8,12	9500	4	4750	144
3400	600	(M. Mio.) Temblor Ss.		8,12	10,500	4	5250	147
4000	800	(Olig. & Eo.) Kreyenhagen Sh.		8,12	10,000	4	5000	144
4800	200	(Eo.) Gatchell Ss.		8,12	10,500	4	5250	147
5000	600	U. Cret. Moreno Sh.		8,12	11,500	4	6325	150
5600	1800	Panoche Brown Mts. Ss.		8,12	12,500	6	6875	156
7400	700	Ragged Valley Sh.		8,12	12,000	6	6600	153
8400	800	Joaquin Ridge Ss.		8,12	14,000	6	7700	162
9200	100	Basement		8,12	15,000	6	9750	162
9300	10,000			8,12	19,000	6	12,350	170

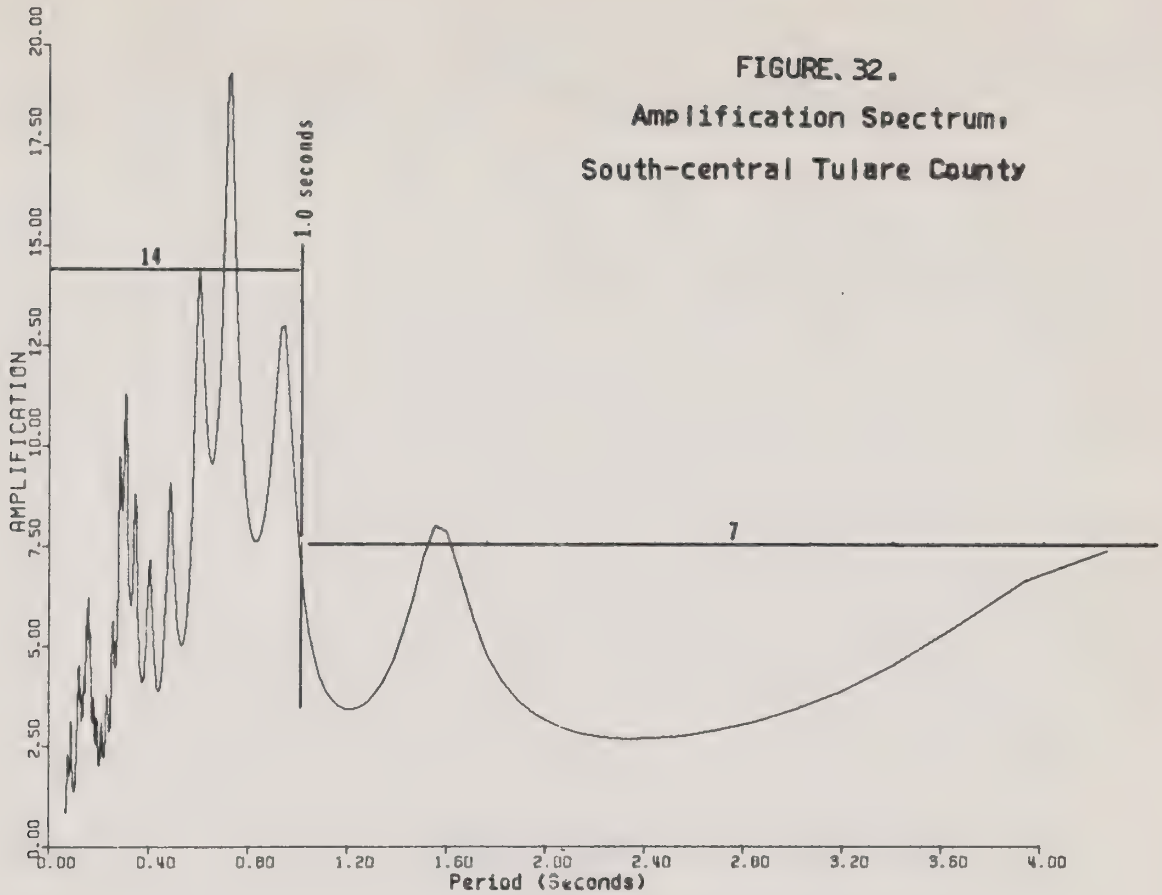


FIGURE. 32.
Amplification Spectrum,
South-central Tulare County

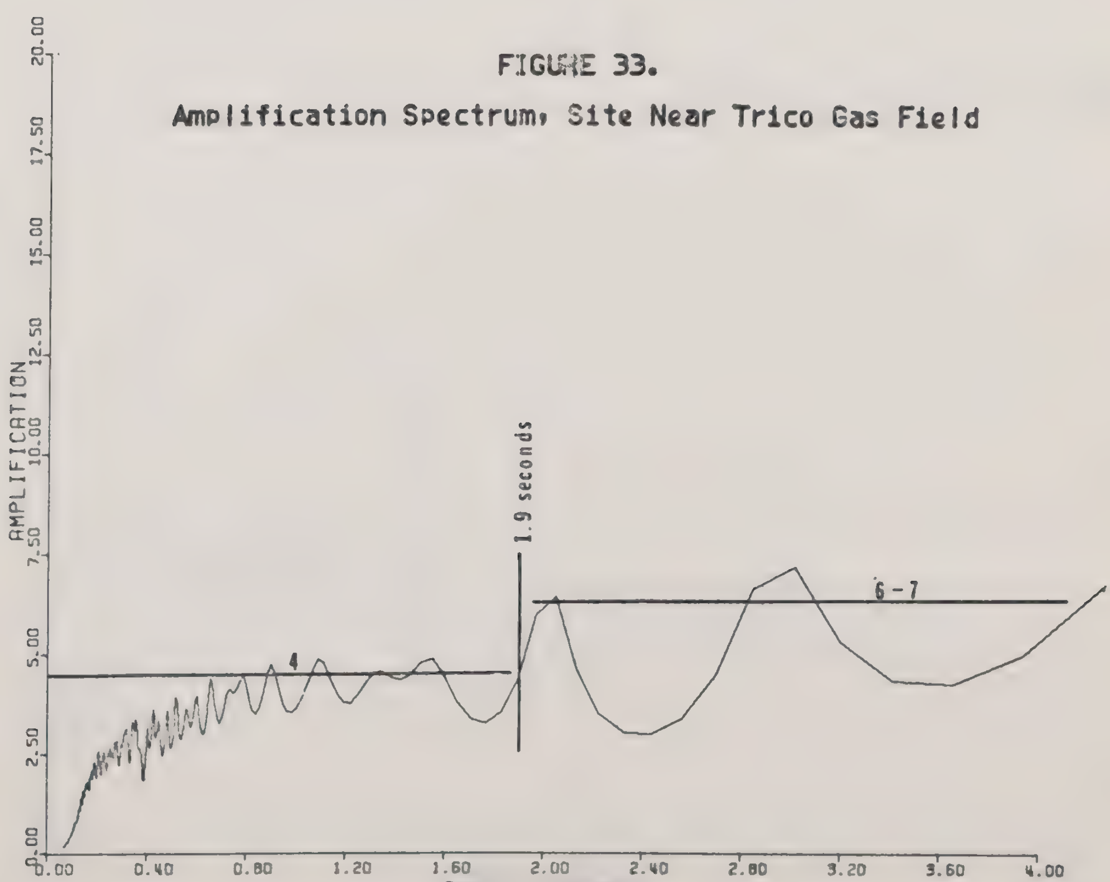


FIGURE 33.
Amplification Spectrum, Site Near Trico Gas Field

SOURCE: ENVICOM

FIGURE 36.

Amplificatior Spectrum, Site Near Hanford

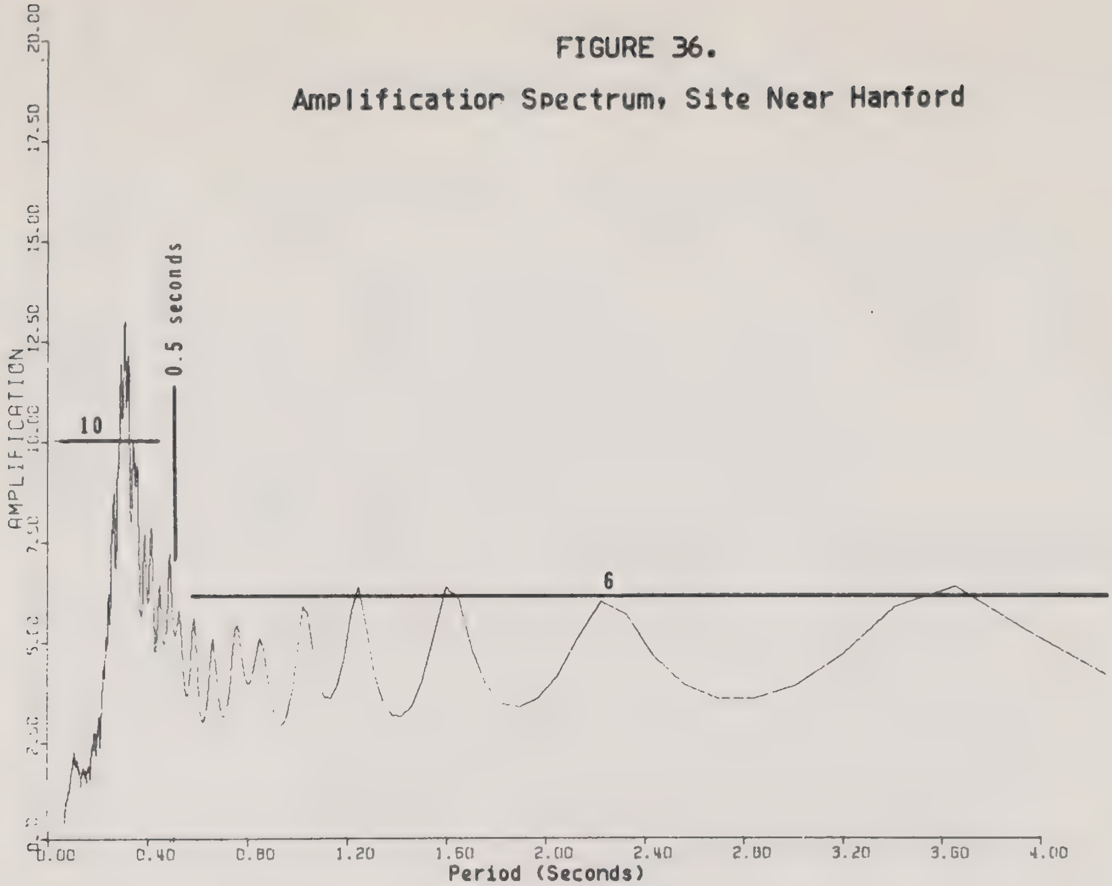
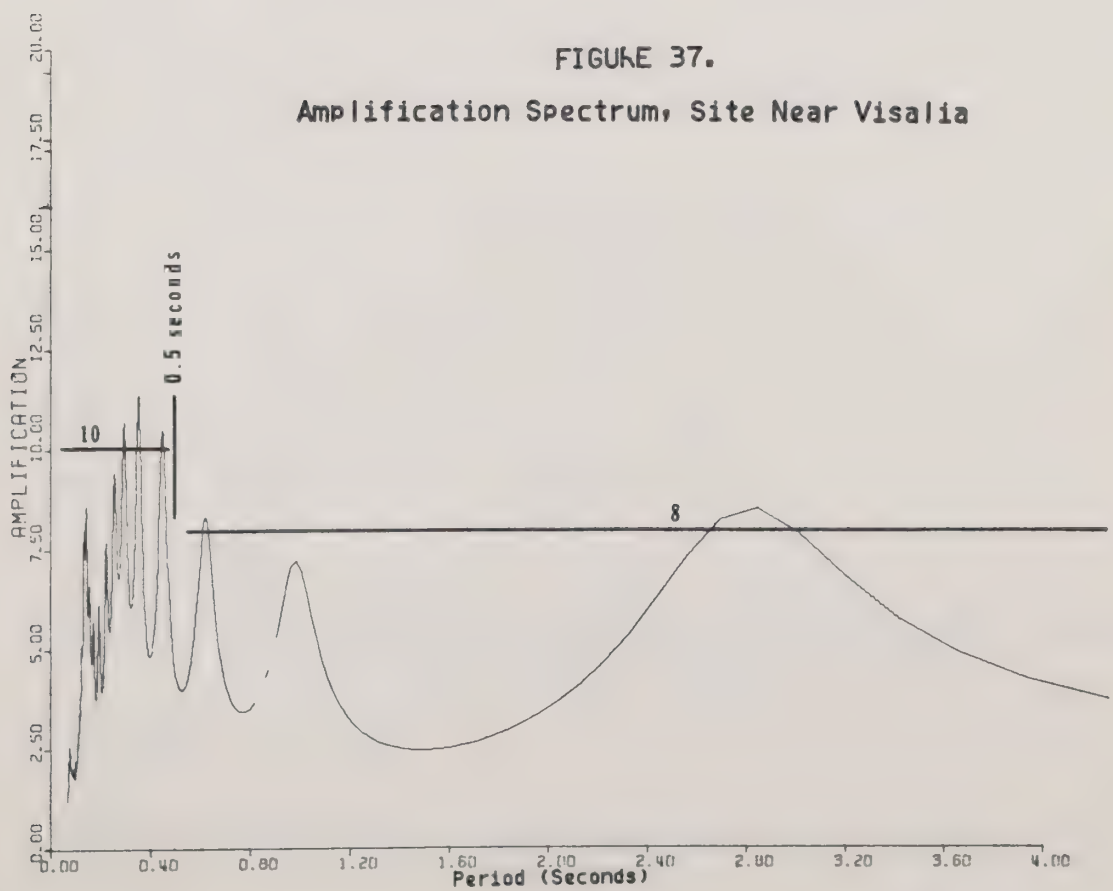


FIGURE 37.

Amplification Spectrum, Site Near Visalia



SOURCE: ENVICOM

FIGURE 38.

Amplification Spectrum, Cantua Creek

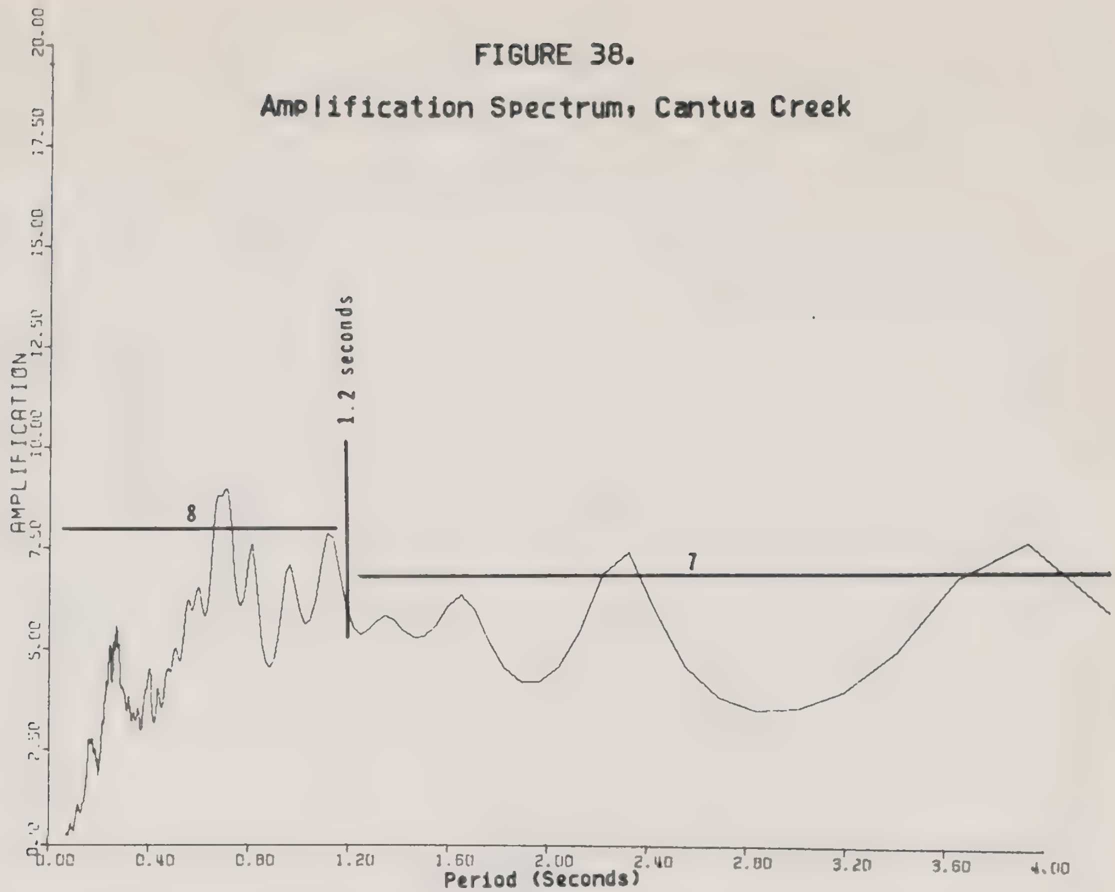
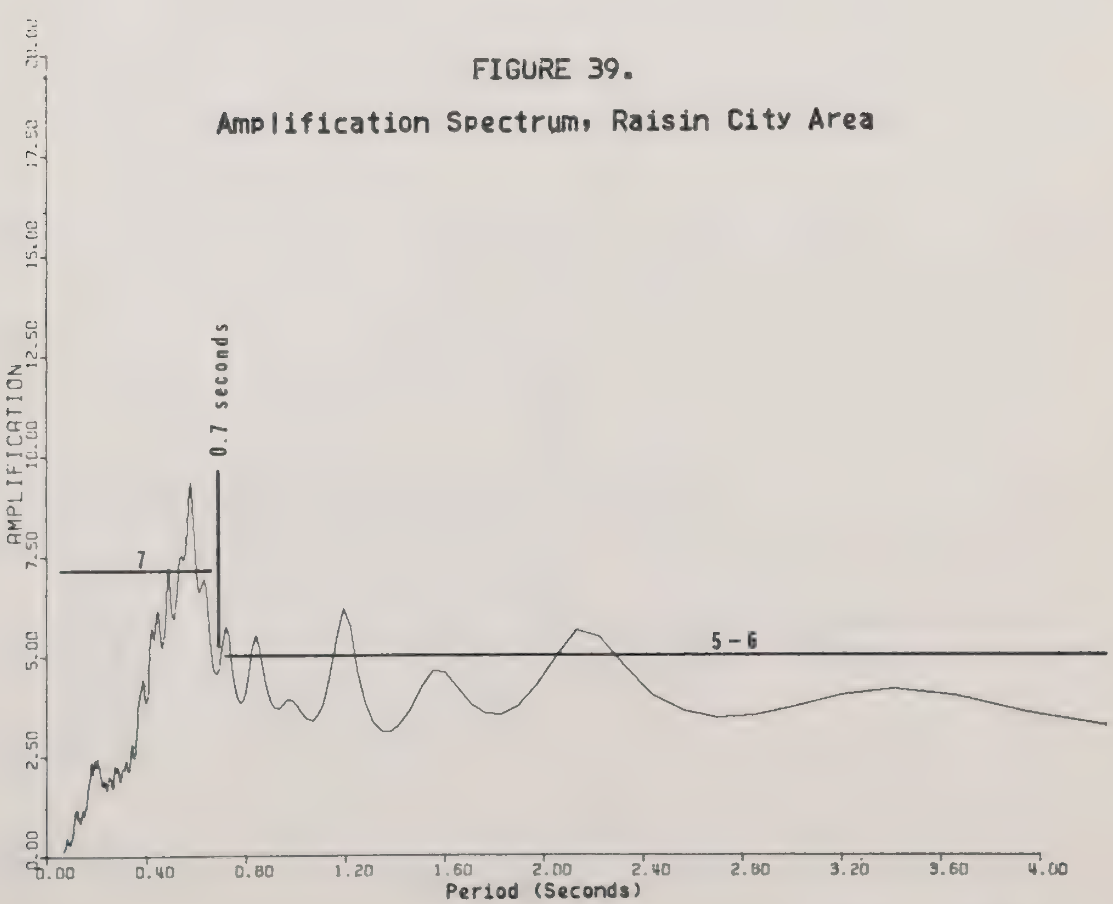


FIGURE 39.

Amplification Spectrum, Raisin City Area



SOURCE: ENVICOM

FIGURE 40.
Amplification Spectrum, Fresno Area

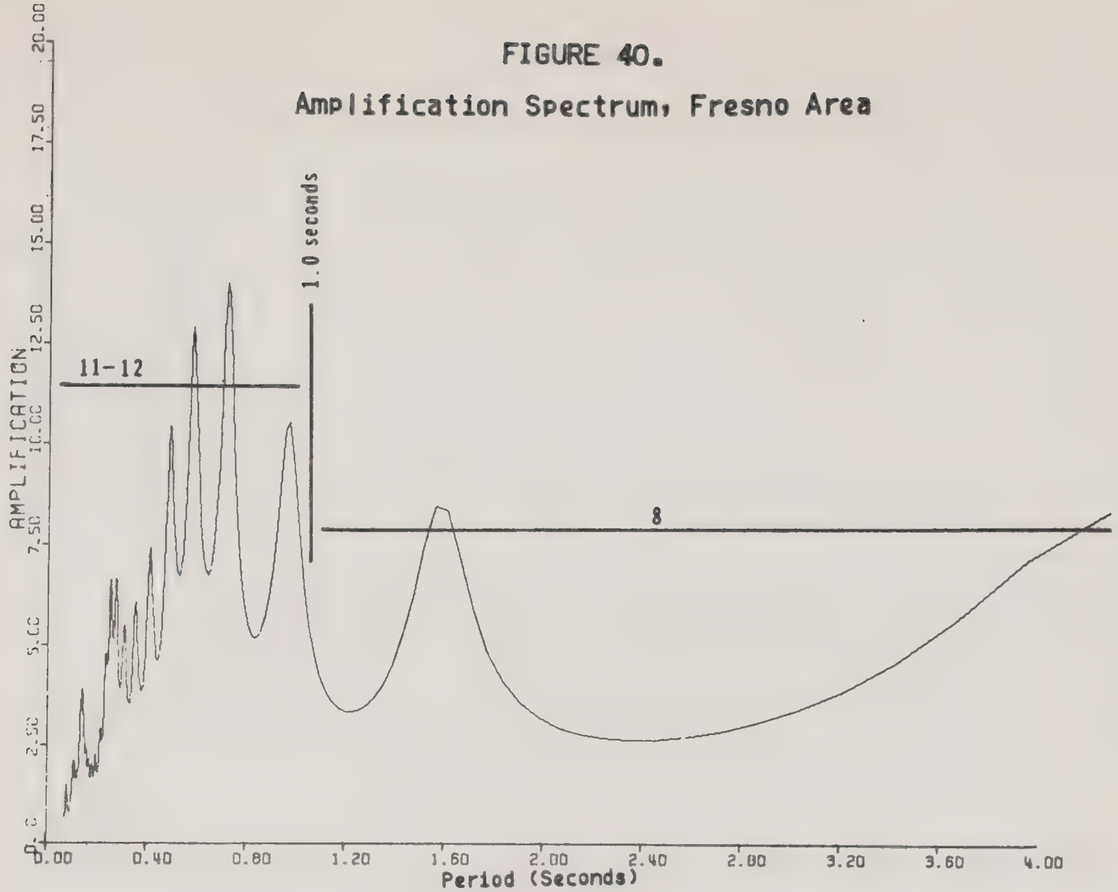
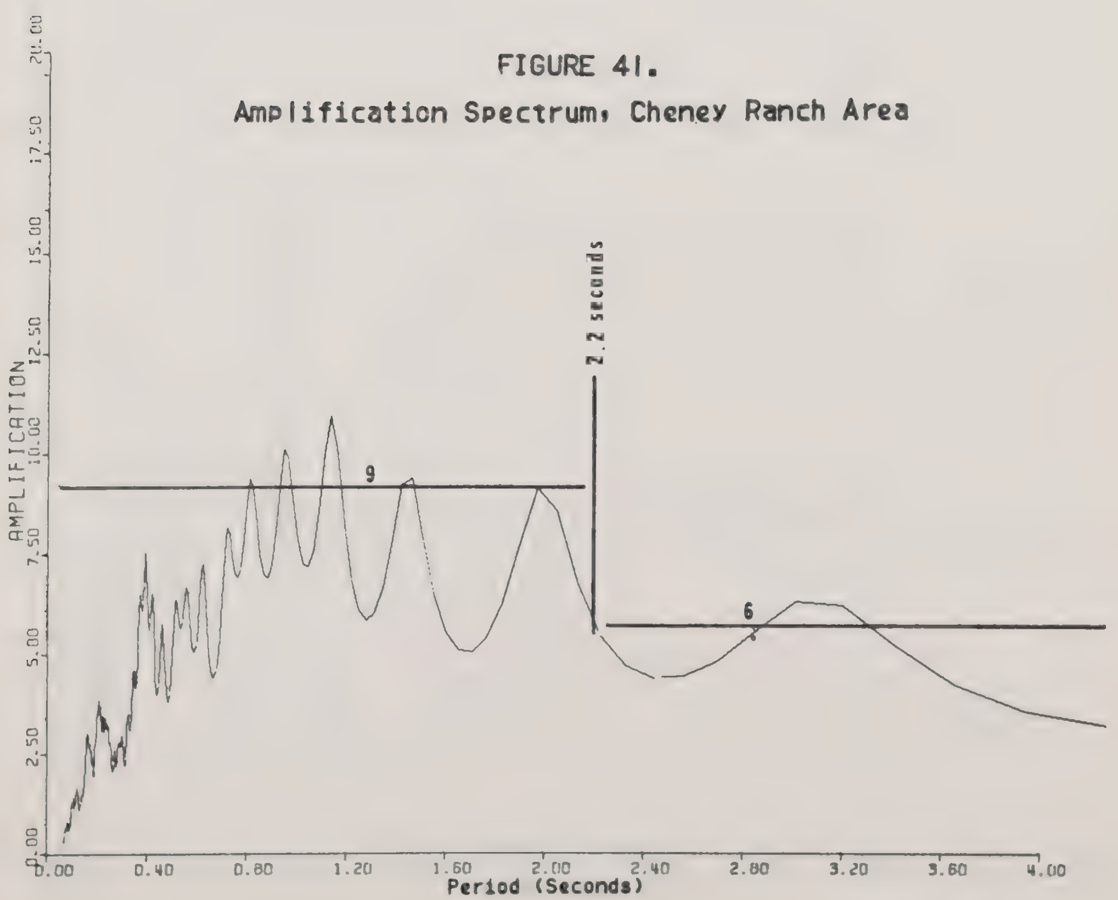


FIGURE 41.
Amplification Spectrum, Cheney Ranch Area



SOURCE: ENVICOM

FIGURE 42.

Amplification Spectrum, Gill Ranch Area

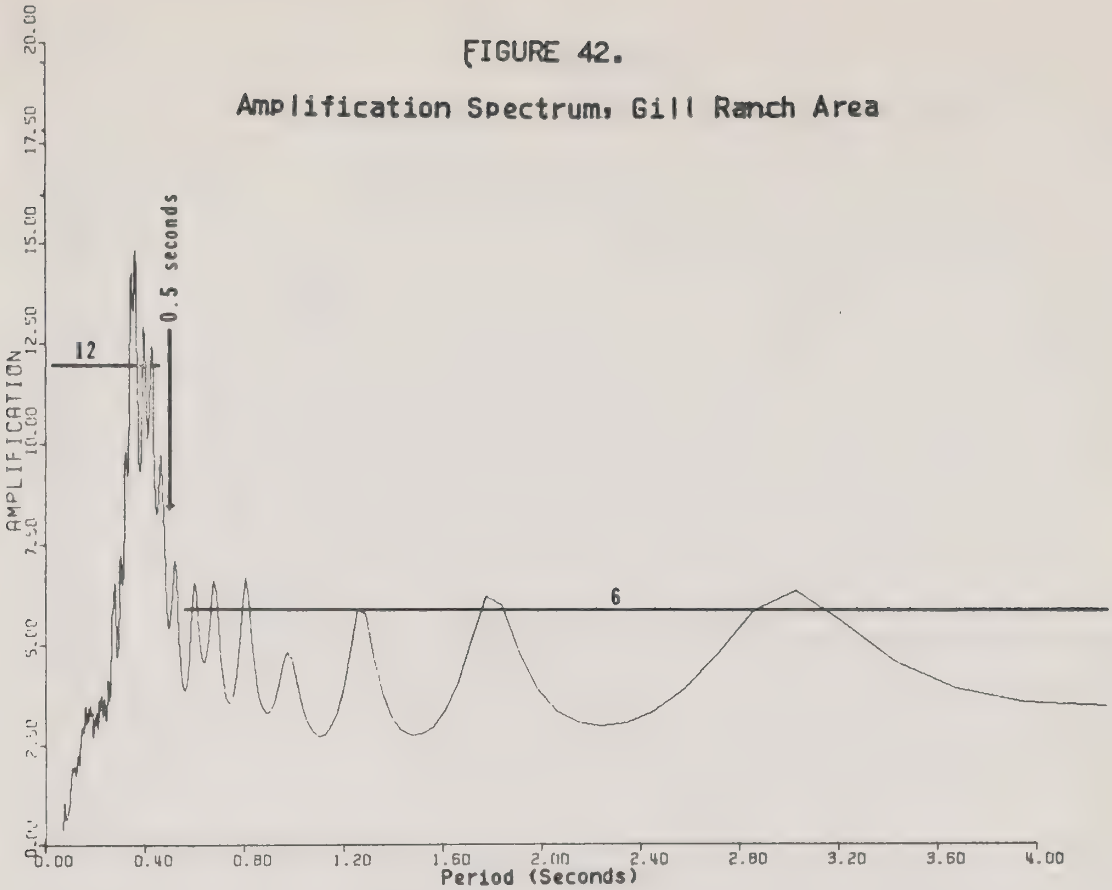
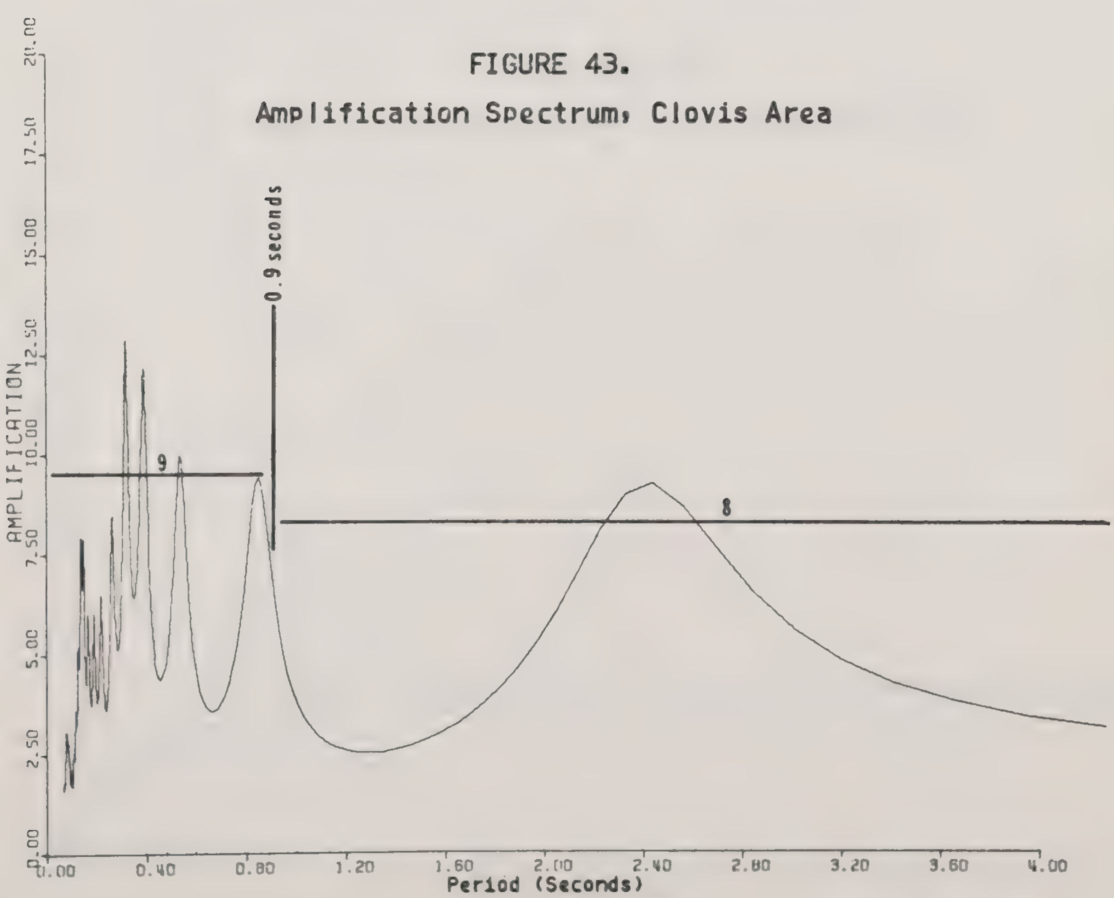


FIGURE 43.

Amplification Spectrum, Clovis Area



SOURCE: ENVICOM

FIGURE 44.

Amplification Spectrum, North-central Area

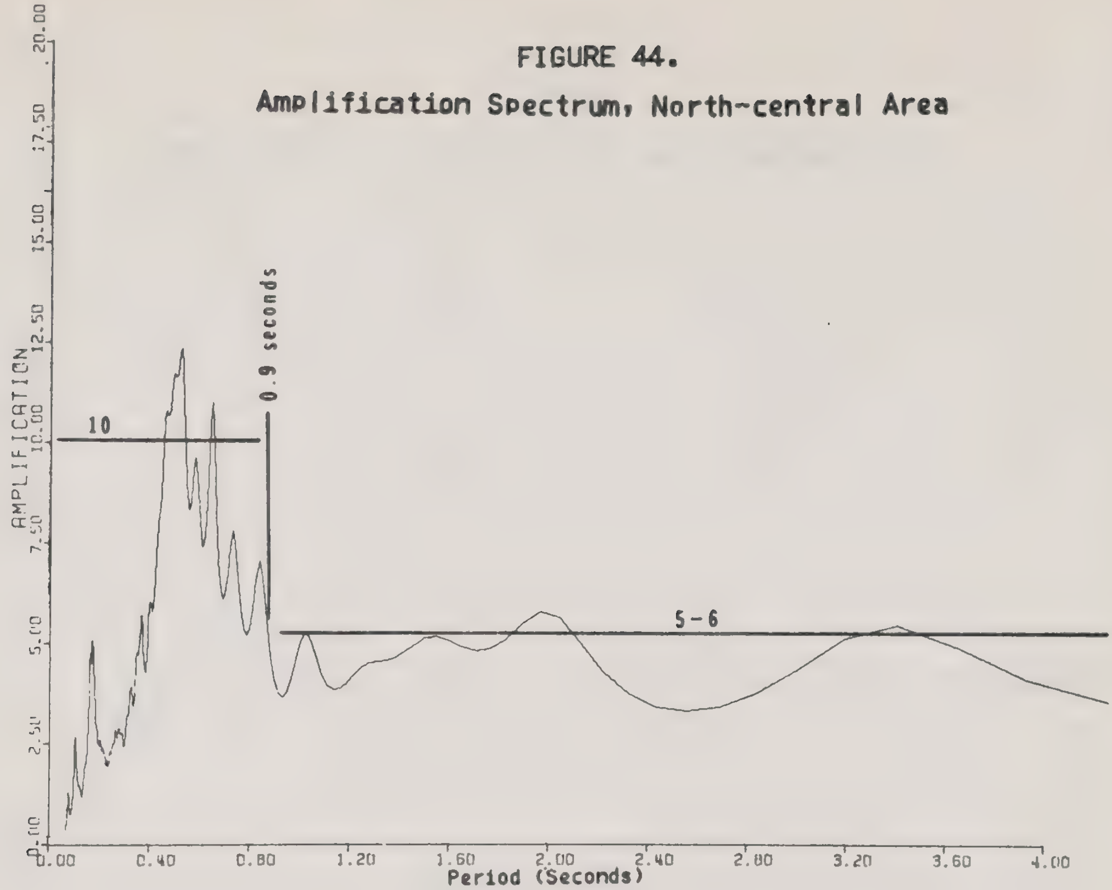
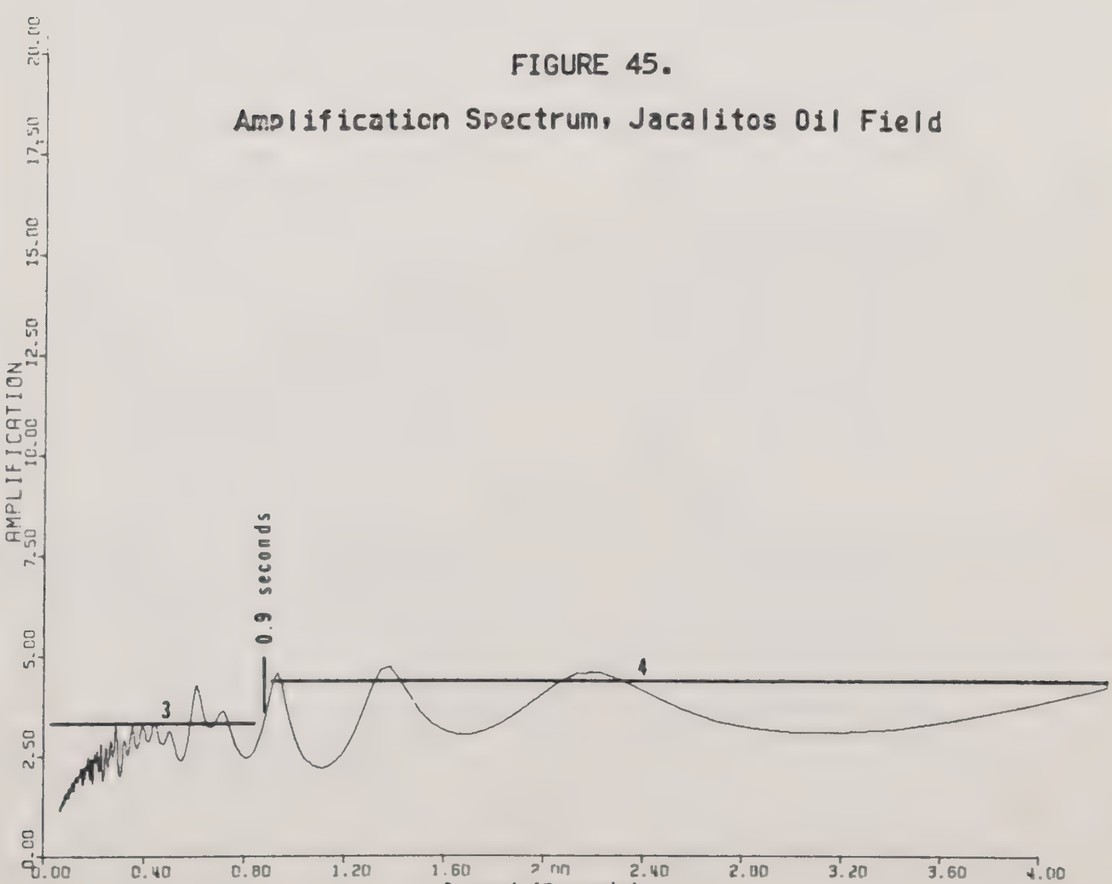


FIGURE 45.

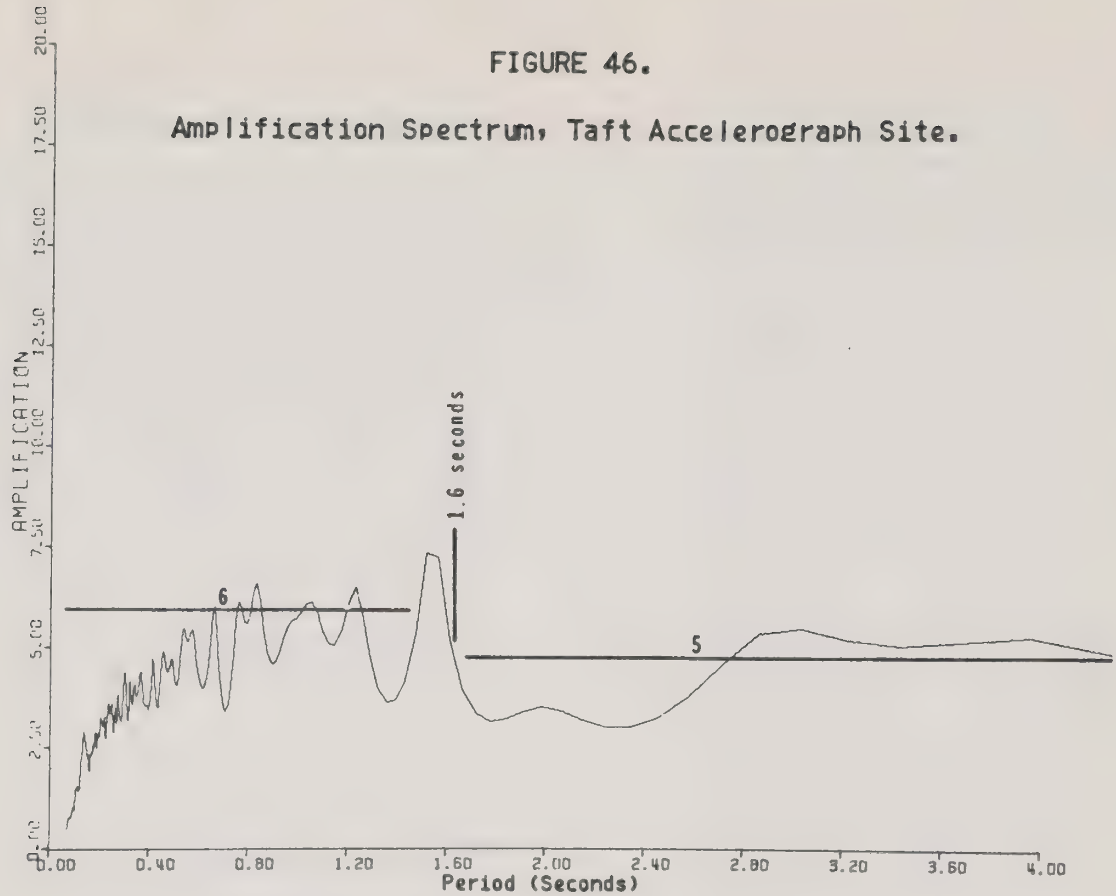
Amplification Spectrum, Jacalitos Oil Field



SOURCE: ENVICOM

FIGURE 46.

Amplification Spectrum, Taft Accelerograph Site.



SOURCE: ENVICOM

d. Microzonation

1. Methodology

The expected ground motion at various sites within the Five-County area is presented as the spectra of this motion plotted as a function of period. As developed in the Introduction (section 7), these spectra represent the expected shaking in terms of the response of simple structures (i. e. single-degree-of-freedom oscillators). The intent is not to define the motion of any particular structure, but to present the expected motion in a way meaningful to the engineer. The more general descriptors of the ground motion, maximum ground acceleration, etc., are derived from the spectra or other data used in development of the spectra.

The spectrum of the ground motion at a site within the Five-County area can be computed using the following equation:

$$S_{V2} = S_{V1} \frac{d_1 A_2}{d_2 A_1}$$

where: S_{V2} = velocity spectrum at the site
S_{V1} = velocity spectrum of the "type earthquake,"
d_1 = distance, in bedrock, of the "type earthquake" record from the earthquake source,
d_2 = distance in bedrock, of the site from the earthquake source,
A_1 = amplification spectrum of site of the "type earthquake" record, and
A_2 = amplification spectrum of the site.

In the equation above, the distance factors are simplified from a more complex equation assuming cylindrical spreading from a line source and negligible damping in bedrock (granite or Franciscan metamorphic rocks). The spectral relationships are based on linear system theory (Duke et al, 1970) valid for the Fourier spectra of the ground motion. Their application to the response spectra of the ground motion at values of 0-10% of critical damping is an approximation considered adequate for the generalization necessary in zoning an area the size of the Five-County area.

Discussion of the microzoning of the area is divided into three sections based on the distinctly different near-surface amplification characteristics in the major three physiographic provinces. The zoning in San Joaquin Valley and the western coastal mountains is the most complex because thick layered sequences are involved, and most of the people live there. The zoning in the Sierra Nevada is, to a first approximation, relatively simple because of the relatively minor changes in the physical characteristics of the bedrock. However, the more populated areas in the Sierras are often located on the alluvium of the meadows which introduces additional complexities.

2. San Joaquin Valley Zones

Ground motion in the San Joaquin Valley will be controlled by distance to the San Andreas fault and the variation in near-surface amplification. Analysis of the latter indicates that the amplification characteristics of the 13 sites in the Valley (Figure 34 through 46) vary primarily with the thickness of the sedimentary section beneath the site. Short-period amplification varies from an average of approximately 12 in the east valley area (Sites 1, 6, 9, and 12) to an average of 8 in the central and west-valley areas (Sites 5, 7, 8, 10, 11, and 13), and has the unusually low value of 4 in the Tulare Lake area (Sites 2 and 3). The long-period amplification also decreases westward, but at a much lower rate. Values on the east side (Sites 1, 6, 9, and 12) average about 8, while those in the central and west (Sites 2, 3, 4, 5, 7, 8, 10, 11 and 13) average about 6.

The averaging of the amplification characteristics as discussed above is a necessary step in applying the results of a detailed analysis of a few sites to the evaluation of a large area. In this case, comparison of the amplification spectra derived by the modeling process with the characteristics of the models indicates that the major variations in amplification are controlled by variations in the thickness of the sedimentary section. Since the effects of shallow variations in velocity are minor, the results obtained from the individual sites can be extrapolated laterally on the basis of variations in the sedimentary section as determined from wells drilled for oil, and to a lesser extent for water, in the area.

In this system of analysis, the individual sites provide the detailed control from which the larger area can be interpreted from more readily available data. Thus, the distribution of the seismic zones is the result of variations in subsurface geologic conditions and the distance to the source of the expected earthquake, while the engineering characteristics of each zone are based on the numerical results of the detailed analysis of the sites. The results of this system of analysis are compared to experienced intensities of shaking in a later section of this report.

The ground-motion spectra for typical areas in the Valley proper and the Coalinga-Kettleman Plain area have been computed using the equation developed in the previous section and the variation in near-surface amplification discussed above. The "type earthquake" (S_{V1} in equation) is a smoothed envelope (Figure 48) of the spectra of the two horizontal components of the Type A ground motion of Jennings, Housner and Tsai, discussed previously. Distance to the "recorded" ground motion (d_1 in equation) is assumed to be 10 miles for reasons discussed previously. The near-surface amplification of the site of the "type earthquake" (A_1 in equation) is assumed to be approximately the same as that for Taft (Figure 48), which was generated using the model of Lastrico (1970). The distance to the causative fault (d_2 in equation) and the generalized area amplification characteristics (A_2 in equation) are summarized in Table 25. The applicable ranges of period shown in the table are approximate, and some smoothing is necessary in deriving the response spectra shown in Figures 49 through 55.

Comparison of the seven spectra indicates that the first four are very similar and can be combined into one zone, designated VI. The similarity of these areas is due to the decrease in near-surface amplification toward the southwest, which is the same direction that ground shaking would normally increase due to decreasing distance to the causative fault. The spectrum for the Tulare Lake area, zone V2, is similar to those of zone V1, but is lower in the short-period range because of the usually low amplification of this range.

Zones V3 and V4 are based on the Cantua Creek and Coalinga-Kettleman Plain spectra. Both zones have lower amplification than zones to the northeast, but it is not sufficient to outweigh the decrease in distance to the San Andreas fault.

The boundaries of the four valley zones are somewhat arbitrary. The low short-period amplification of zone V2 appears to be related in part to the old lake beds, and the boundary of the zone is defined on this basis. The boundary between zones V3 and V2 is gradational. It is placed further to the northeast in the Mendota-Firebaugh area because of the higher amplification factors at sites 10, 11 and 13 as opposed to those at sites 7 and 8. The boundary between zones V3 and V4 is based primarily on distance to the San Andreas fault, and is also gradational. The resulting valley zones are shown on Plate I, and the general characteristics of the ground motion and a typical spectrum for each zone are shown on Table 26.

3. <u>Coastal Mountain Zones</u>

The coastal mountains were zoned using a procedure very similar to that used in zoning the San Joaquin Valley except that preliminary zones, based on variation in rock types, were defined as a first step. Those zones were defined as follows:

1. Kettleman Trend -- pre-Eocene rocks along the east flank of the mountains in northwest Fresno County, and in the Kettleman Hills.

   Joaquin Ridge -- Eocene and older rocks in northwest Fresno County.

2. Jacalitos Trend -- Pliocene rocks along the east flank of the mountains in southwest Fresno County, and older rocks toward the west.

   Wortham Valley -- Pliocene and some older rocks along the southwest border of Fresno and Kings County.

The objective in defining the preliminary zones as described was to group rocks of similar age and at similar distances from the San Andreas with older rocks having lower near-surface amplification located closer to the fault.

The distance and amplification characteristics of the four zones are given in Table 27, and the resulting response spectra are shown in Figures 56 through 59.

Comparison of the four spectra indicates that those for the Kettleman Trend and Joaquin Ridge can be combined into one zone designated C1. Also, the spectra for the Jacalitos Trend and Wortham Valley are sufficiently similar to be combined as zone C2. The combined zones and the final zone boundaries are shown on Plate I. The general characteristics of the ground motion and a typical spectrum for each zone are shown in Table 26.

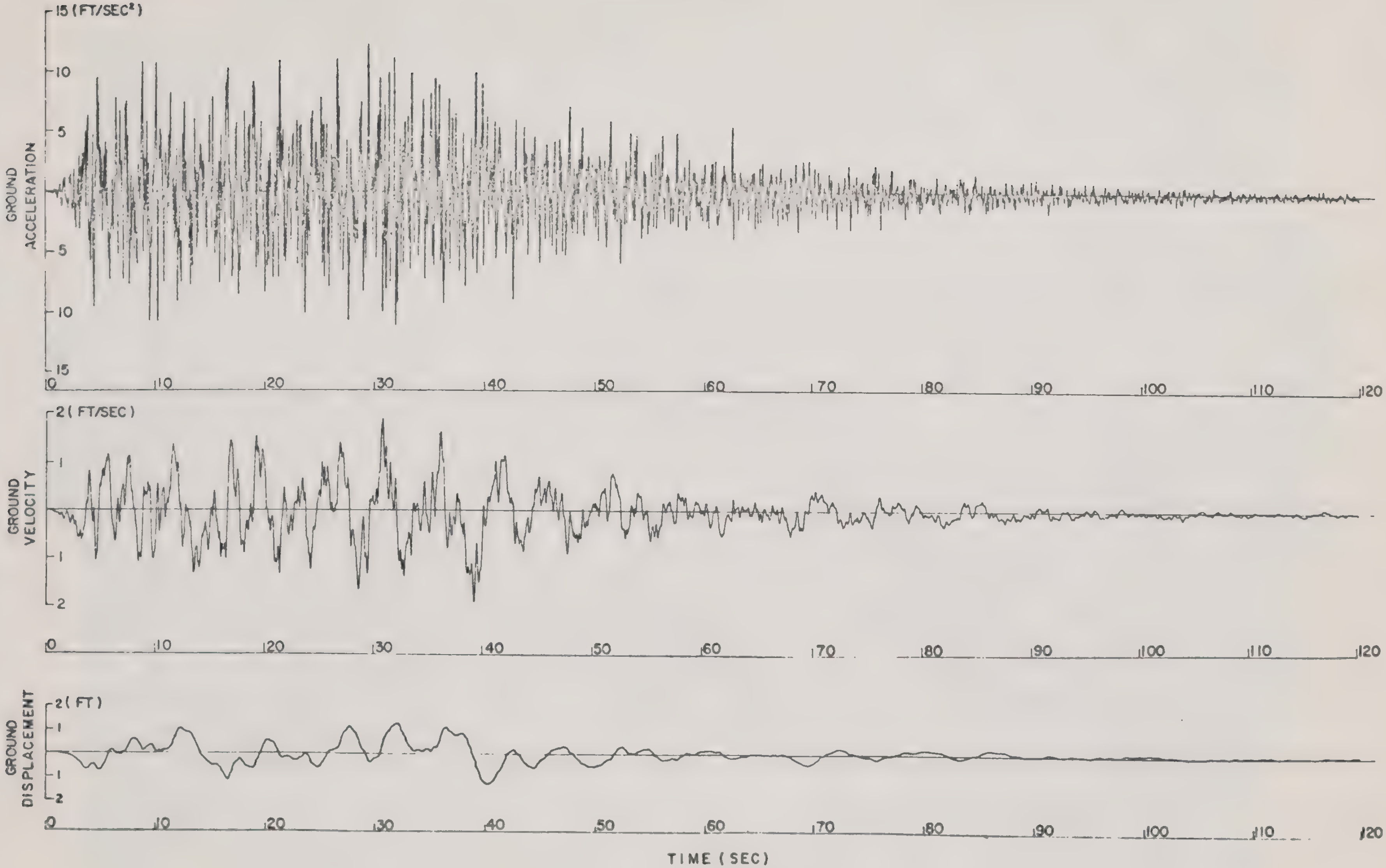


FIGURE 47. EARTHQUAKE A-1

Acceleration, Velocity and Displacement for Earthquake A-1

From Jennings, Housner & Tsai, 1968

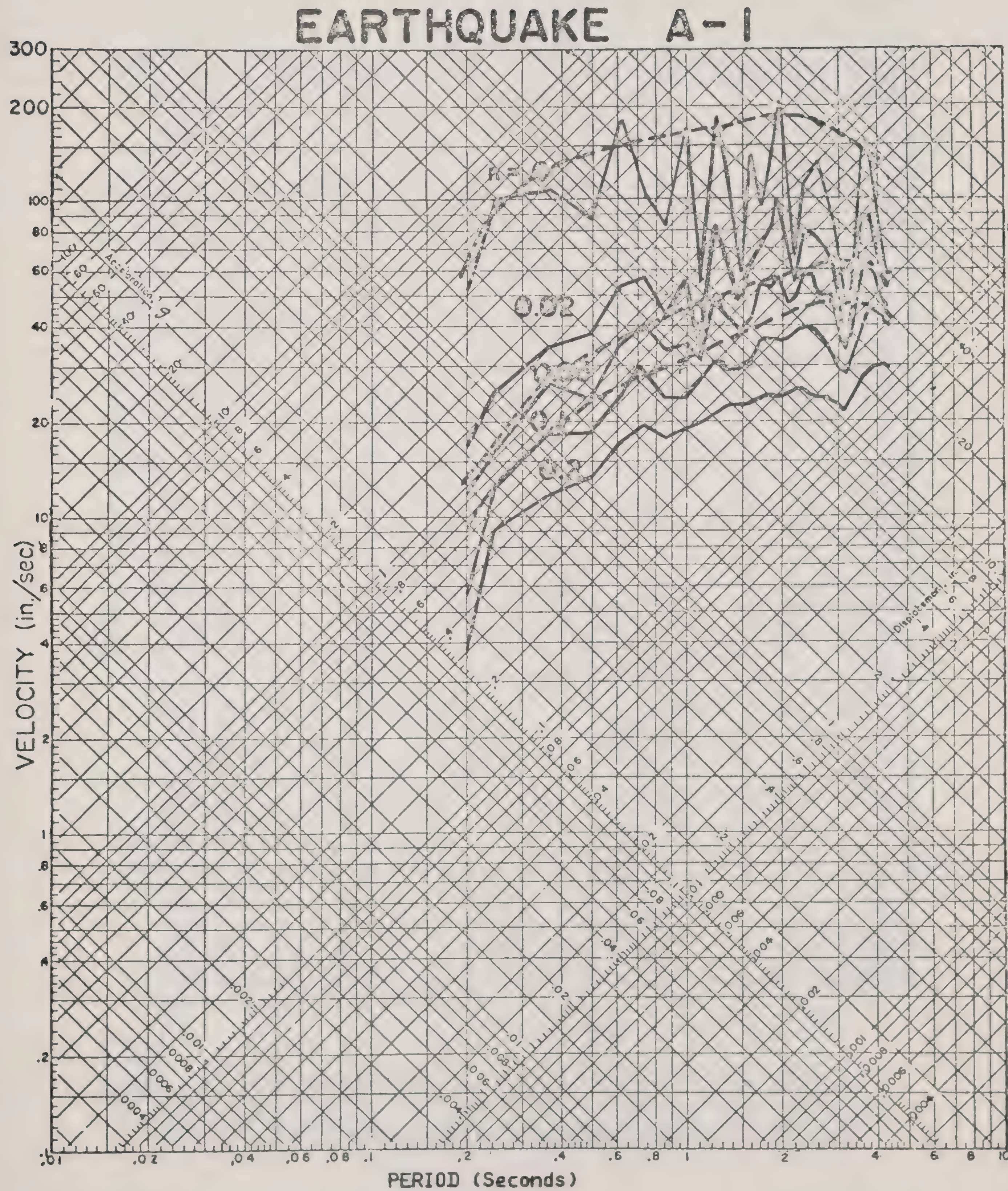


FIGURE 48. Tripartite logarithmic plot of spectra for earthquake A-1 showing smoothed envelopes for 0%, 5%, and 10% critical damping. Based on Jennings, Housner, & Tsai, 1968.

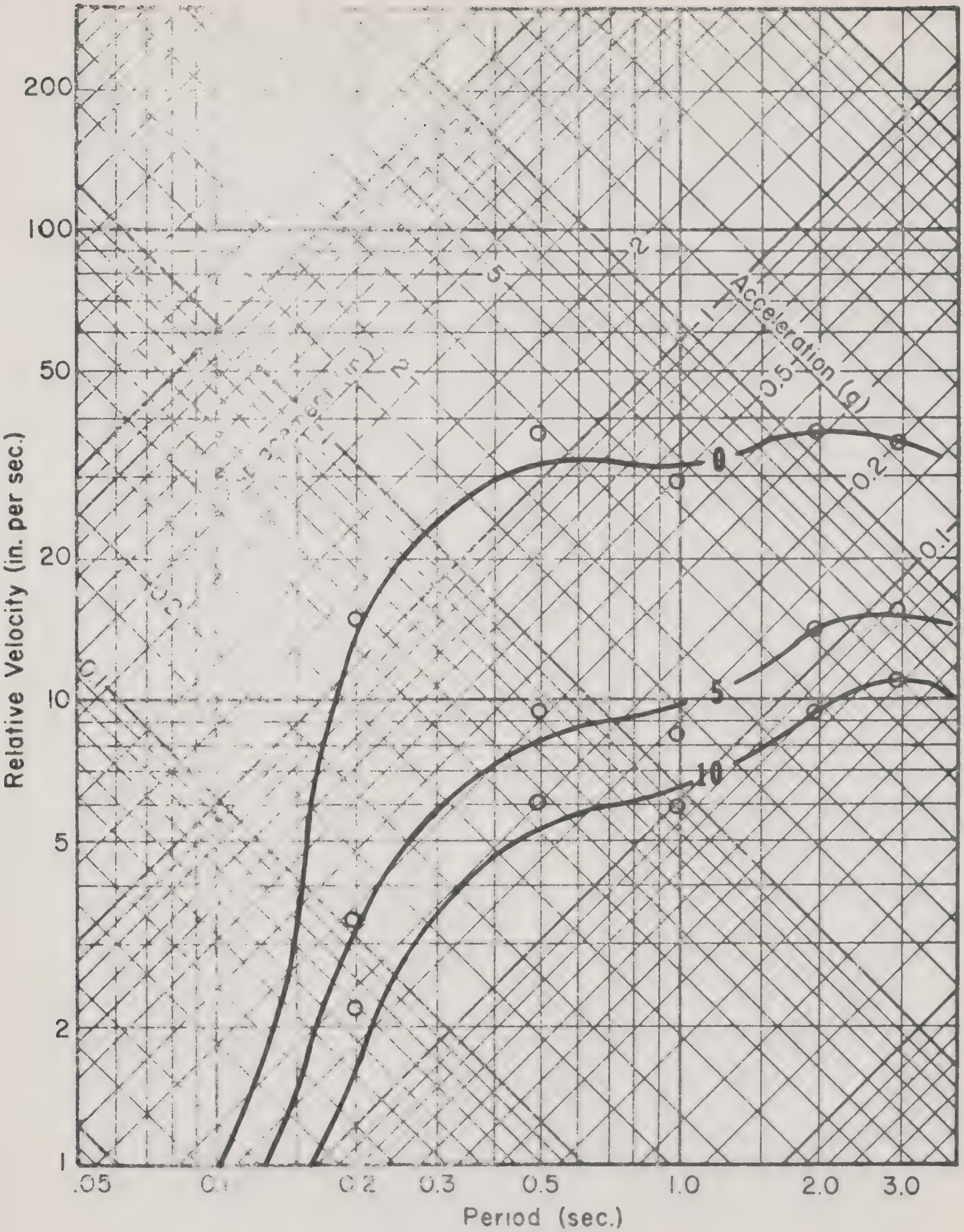


FIGURE 49. RESPONSE SPECTRUM, for 0, 5% and 10% of critical damping.

Fresno-Visalia Trend (Zone VI)

GRAPHICS BY TULARE COUNTY PLANNING DEPARTMENT SOURCE: ENVICOM

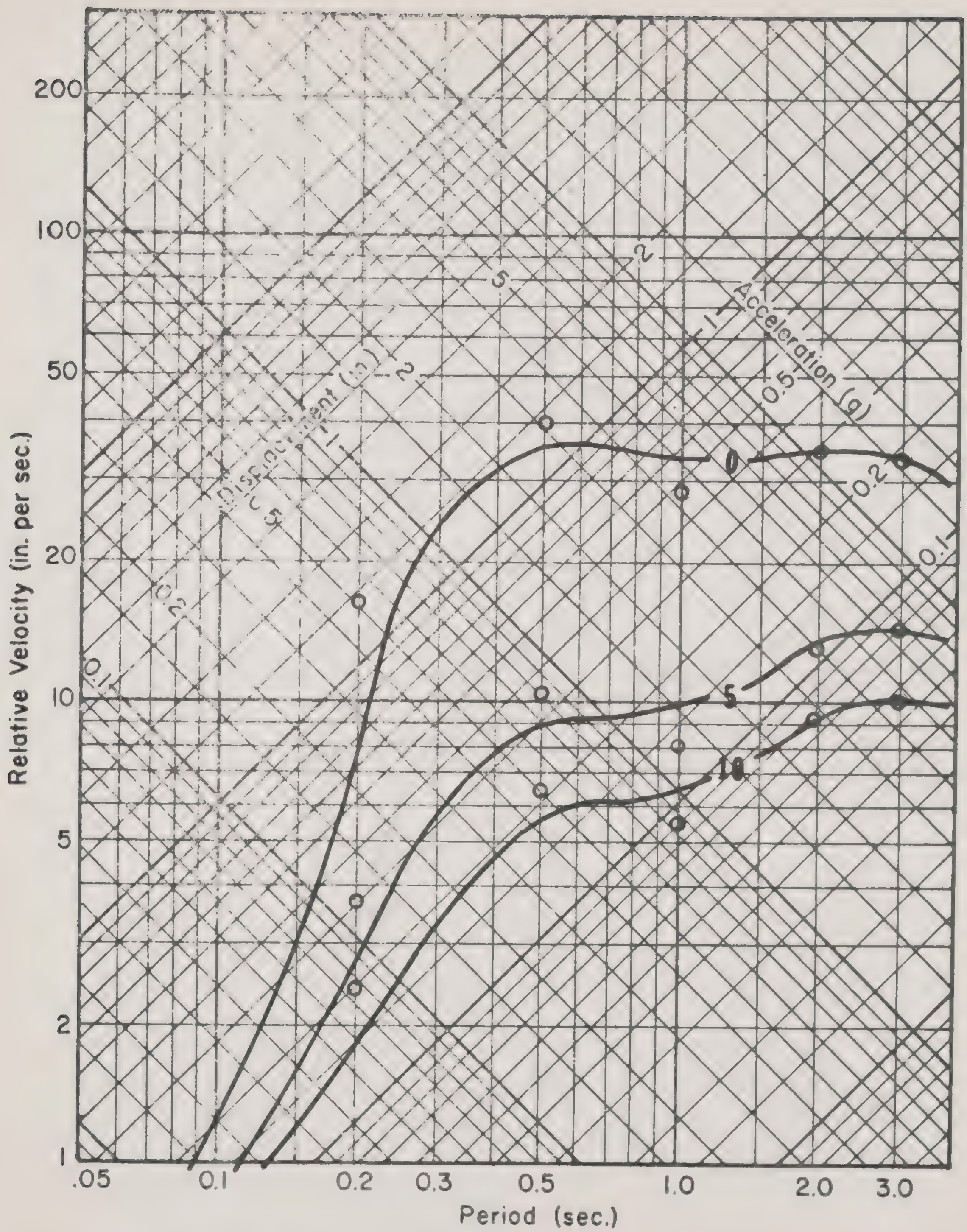


FIGURE 50. RESPONSE SPECTRUM, for 0, 5% and 10% of critical damping.

Hanford Area (Zone VI)

GRAPHICS BY TULARE COUNTY PLANNING DEPARTMENT

SOURCE: ENVICOM

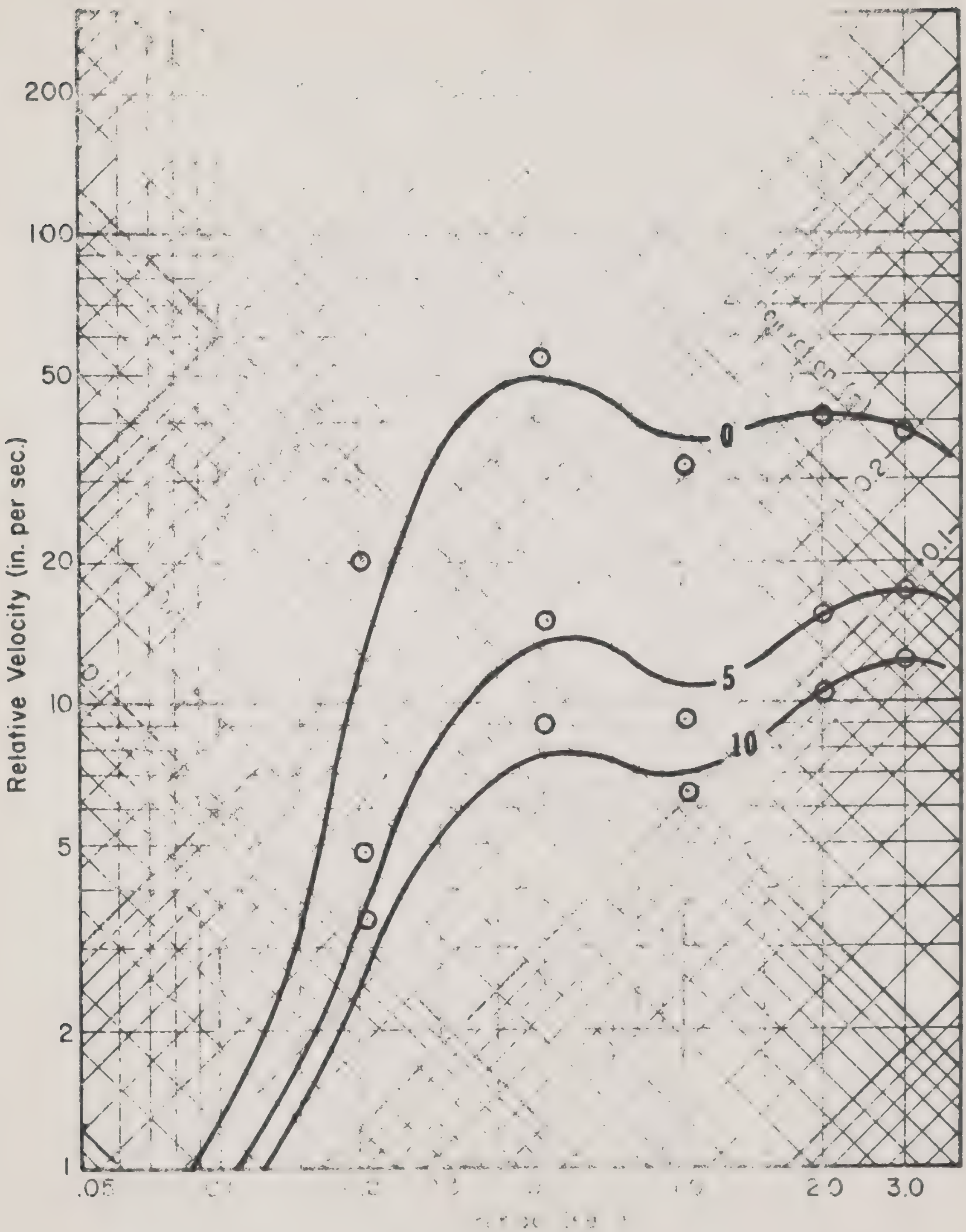


FIGURE 51. RESPONSE SPECTRUM, for 0, 5% and 10% of critical damping.

South-central Tulare County (Zone VI)

GRAPHICS BY TULARE [illegible] SOURCE: ENVICOM

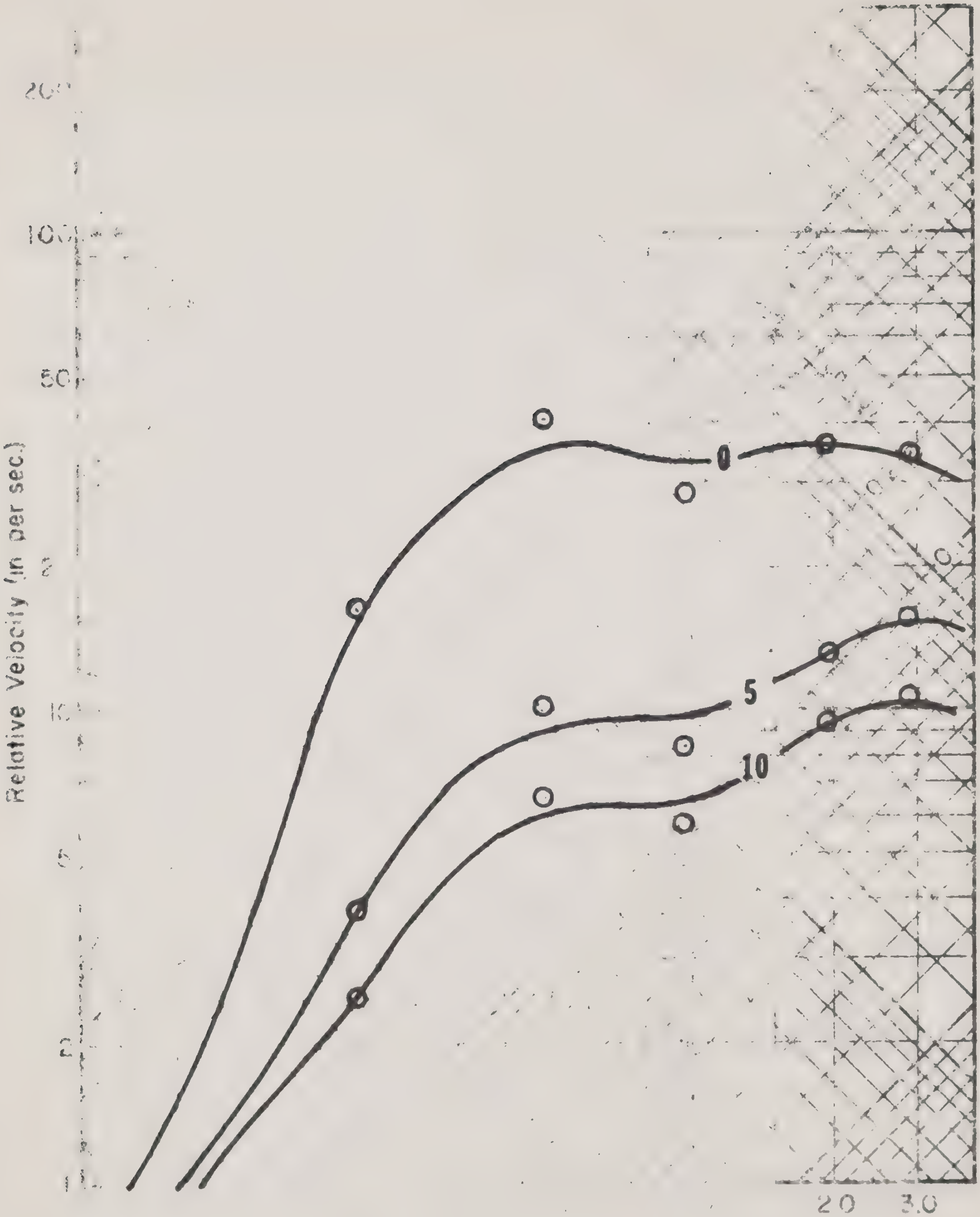


FIGURE 52. RESPONSE SPECTRUM, for 0, 5% and 10% of critical damping, North-central Area (Zone VI)

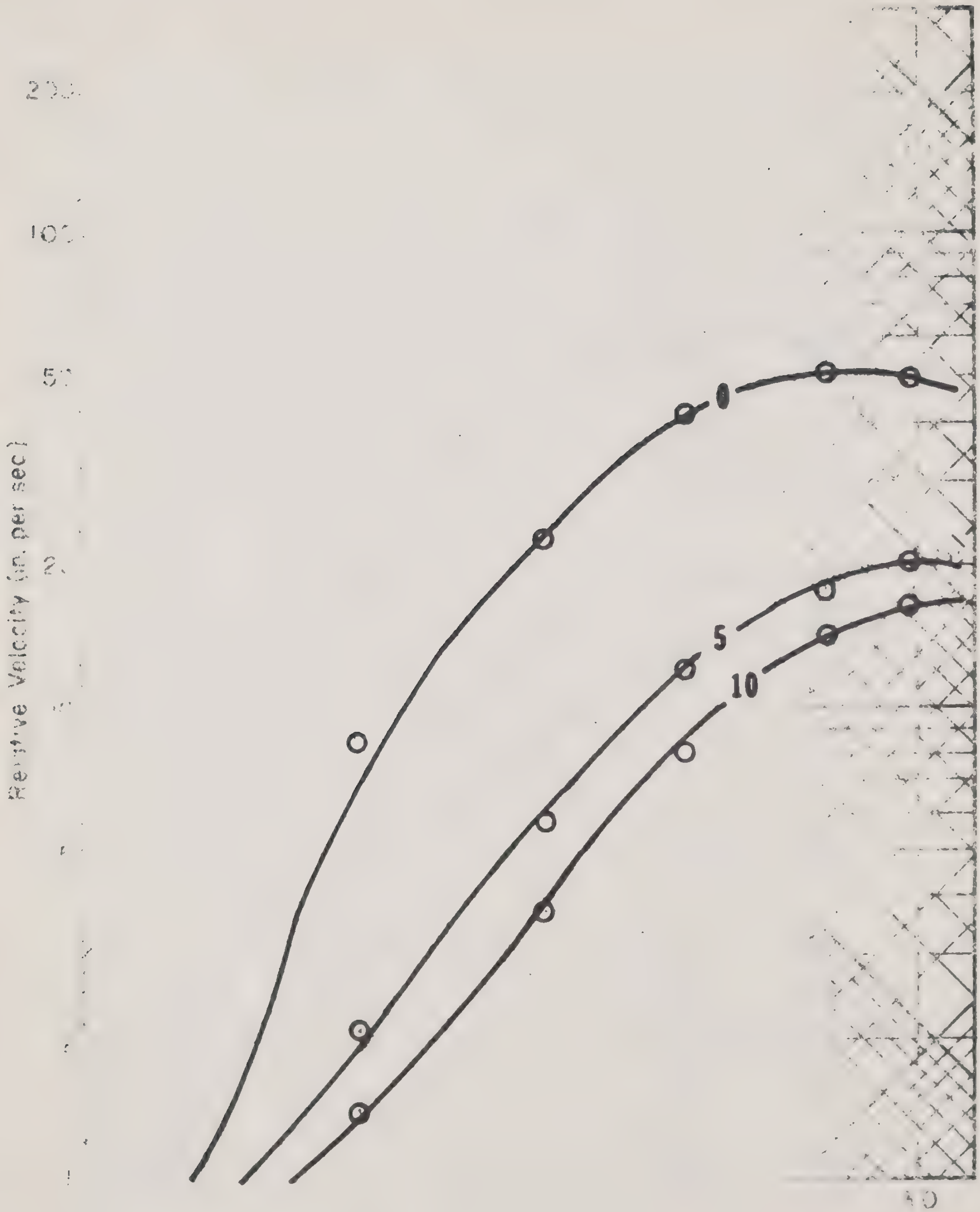


FIGURE 53. RESPONSE SPECTRUM, for 0, 5% and 10% of critical damping.

Tulare Lake Area (Zone V2)

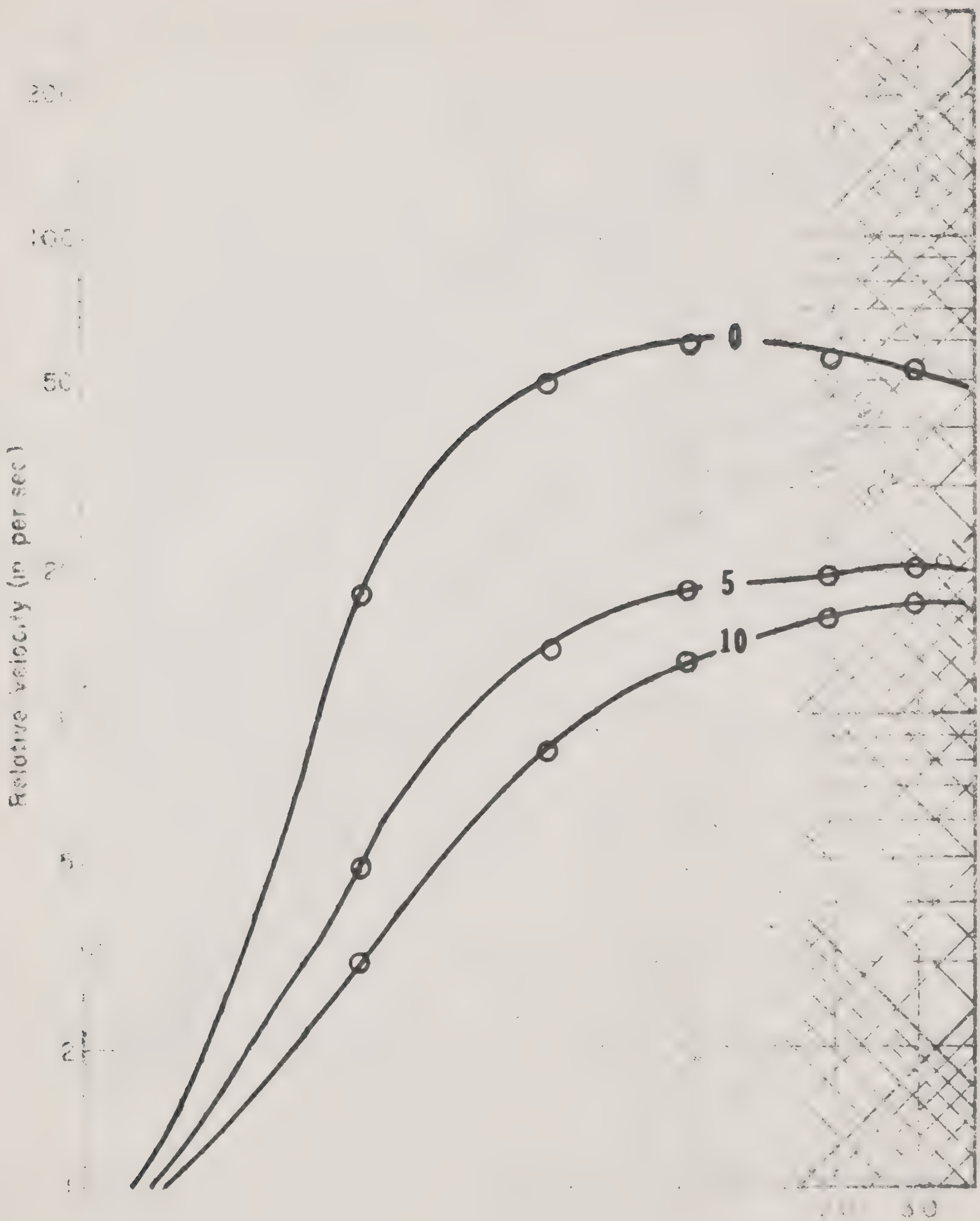


FIGURE 54. RESPONSE SPECTRUM, for 0, 5% and 10% of critical damping.

Cantua Trend (Zone V3)

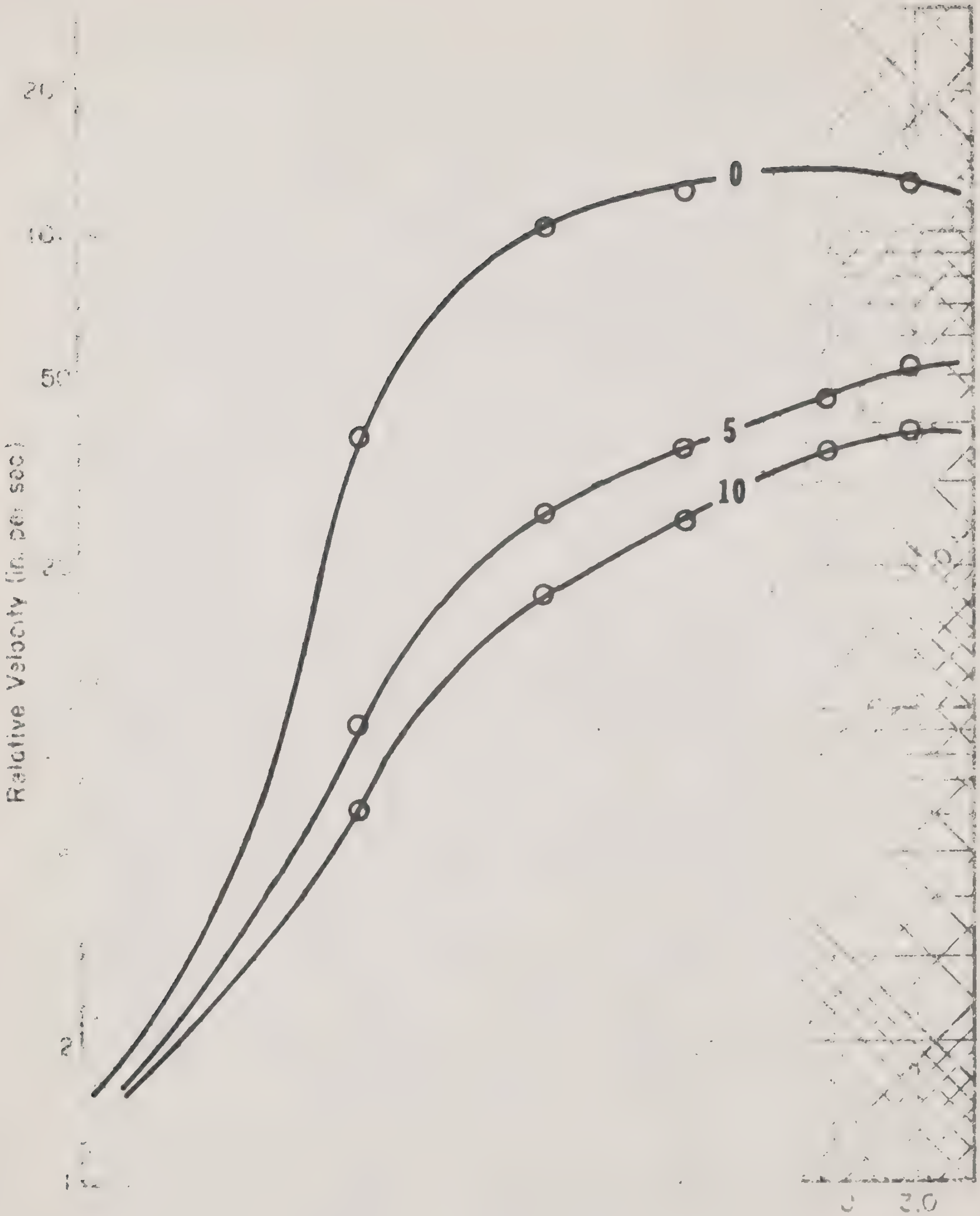


FIGURE 55. RESPONSE SPECTRUM, for 0, 5% and 10% of critical damping.

Coalinga-Kettleman Plain (Zone V4)

TABLE 25
SUMMARY OF DISTANCE AND AMPLIFICATION FACTORS USED IN
COMPUTING GROUND-MOTION SPECTRA IN SAN JOAQUIN VALLEY

Area and Sites Used in Computing A_2	Distance		Near-Surface Amplification and Applicable Range of Period				
			Amplification A_2		Amplification Ratio A_2/A_1		
	d_2	d_1/d_2	Short Period	Long Period	Short Period	Int. Period	Long Period
Fresno-Visalia Trend (Sites 6, 9, and 12)	70 mi	0.14	12 (0-1.0 sec)	8 (1.0-4.0 sec)	2 (0-1.0 sec)	1.33 (1.0-1.6 sec)	1.6 (1.6-4.0 sec)
Hanford Area (Site 5)	54 mi	0.185	10 (0-0.5 sec)	6 (0.5-4.0 sec)	1.67 (0-0.5 sec)	1 (0.5-1.6 sec)	1.2 (1.6-4.0 sec)
So.-Central Tulare Co. (Site 1)	57 mi	0.175	14 (0-1.0 sec)	7 (1.0-4.0 sec)	2.3 (0-1.0 sec)	1.16 (1.0-1.6 sec)	1.4 (1.6-4.0 sec)
No.-Central Area (Sites 11 and 13)	48 mi	0.21	12 (0-0.8 sec)	6 (0.8-4.0 sec)	2.0 (0-0.8 sec)	1 (0.8-1.6 sec)	1.2 (1.6-4.0 sec)
Tulare Lake Area (Sites 2 and 3)	38 mi	0.26	4 (0-1.0 sec)	6 (1.0-4.0 sec)	0.67 (0-1.0 sec)	1 (1.0-1.6 sec)	1.2 (1.6-4.0 sec)
Cantua Trend (Sites 7 and 10)	35 mi	0.285	8 (0-1.6 sec)	6 (1.6-4.0 sec)	1.33 (0-1.6 sec)	--	1.2 (1.6-4.0 sec)
Coalinga-Kettleman Plain (Site 4)	15 mi	0.67	7 (0-1.6 sec)	6 (1.6-4.0 sec)	1.16 (0-1.6 sec)	--	1.2 (1.6-4.0 sec)

TABLE 26
SUMMARY OF GROUND-MOTION CHARACTERISTICS
FOR SAN JOAQUIN VALLEY ZONES

Zone	Maximum Ground Acceleration (Gravity)	Typical Spectrum (See Figure)	Predominant Period (Seconds)	Approximate Duration of "Strong" Shaking (Seconds)
V1	0.13	49	0.2 - 0.4	30
V2	0.1	53	0.5 - 0.9	30
V3	0.2	54	0.4	45
V4	0.4	55	0.4	50
SUMMARY OF GROUND-MOTION CHARACTERISTICS FOR COASTAL MOUNTAIN ZONES				
C1	0.15	57	0.5	40
C2	0.3	59	0.5	50

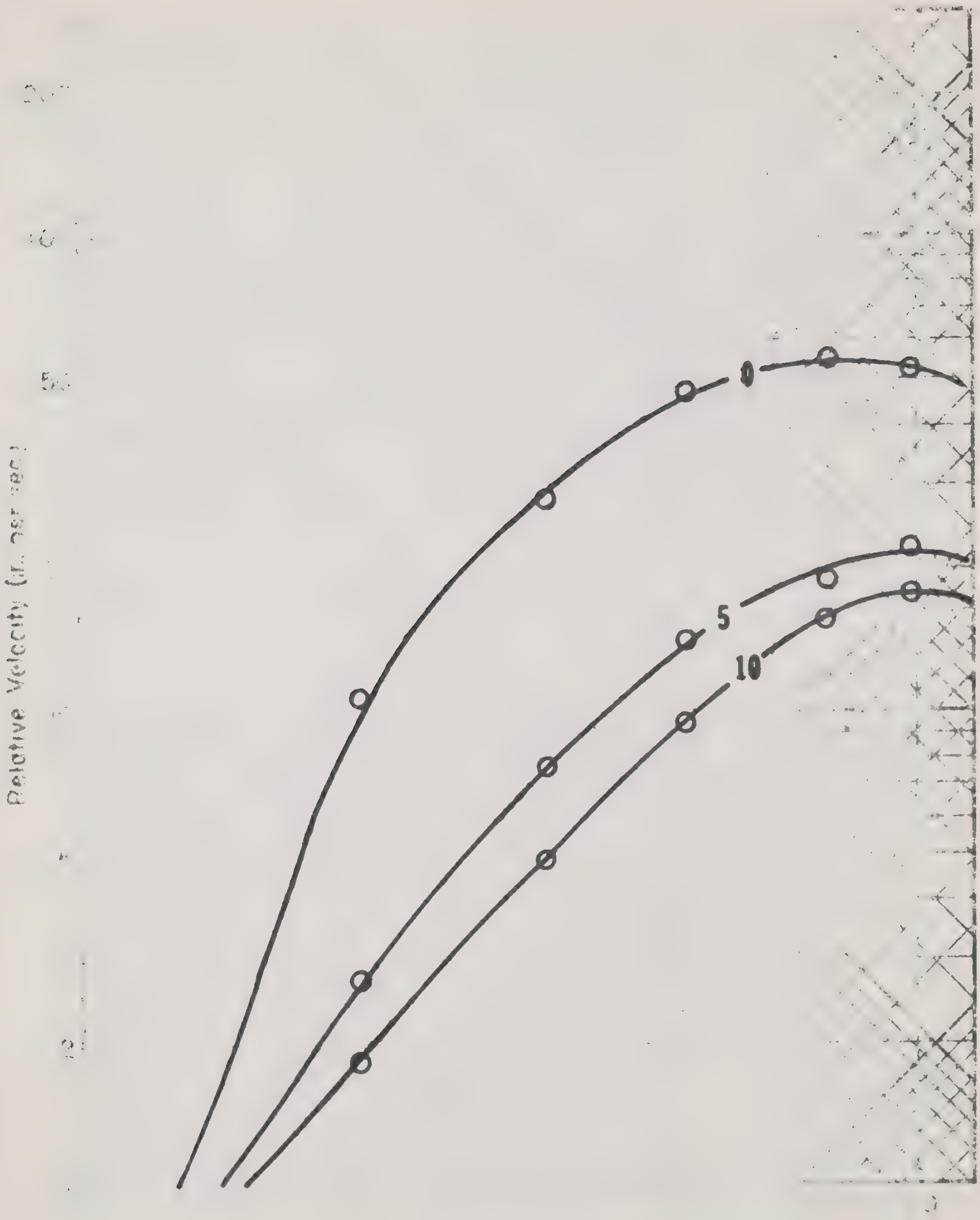


FIGURE 56. RESPONSE SPECTRUM, for 0, 5% and 10% of critical damping.

Kettleman Trend (Zone C1)

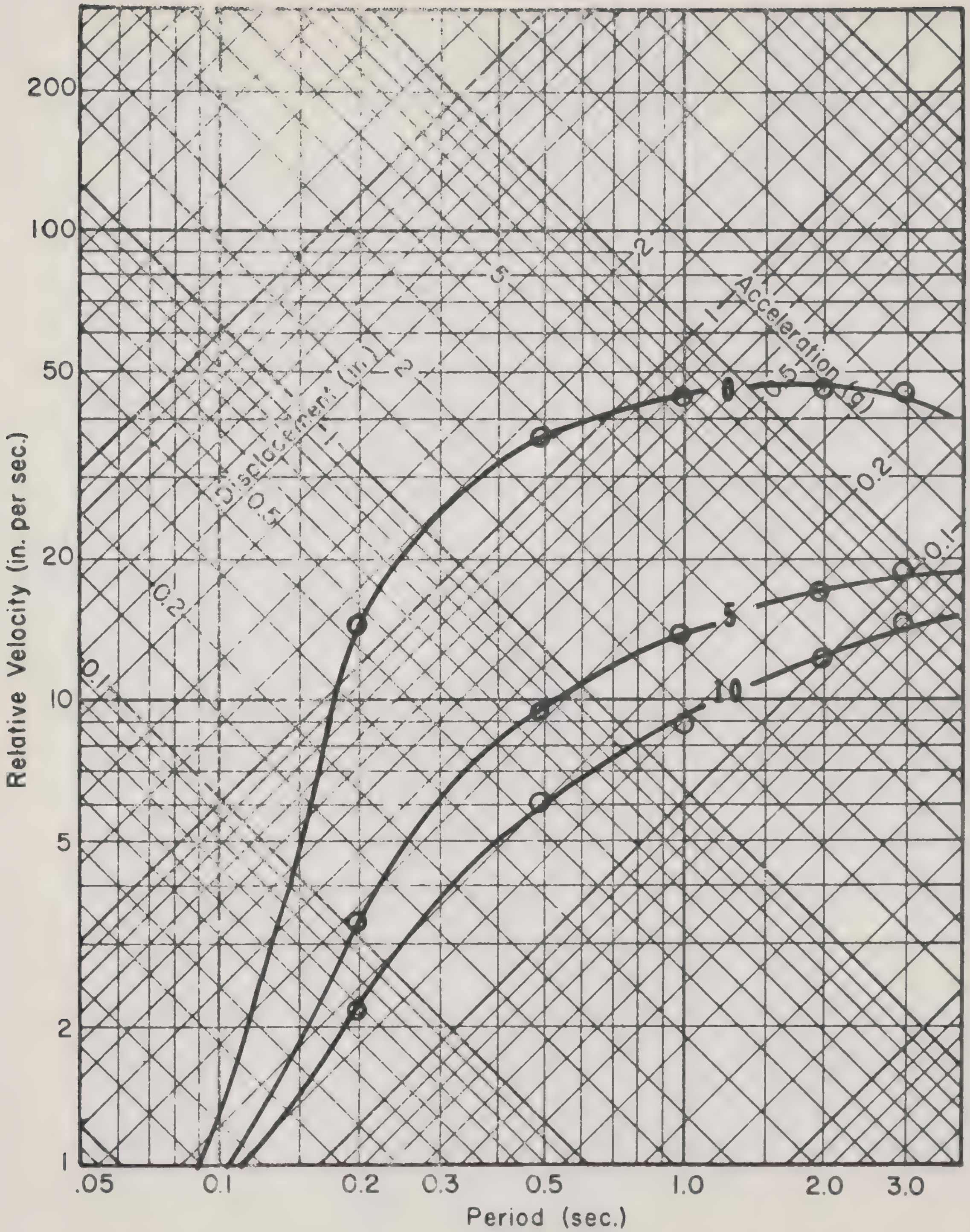


FIGURE 57. RESPONSE SPECTRUM, for 0, 5% and 10% of critical damping.

Joaquin Ridge (Zone C1)

GRAPHICS BY TULARE COUNTY PLANNING DEPARTMENT SOURCE: ENVICOM

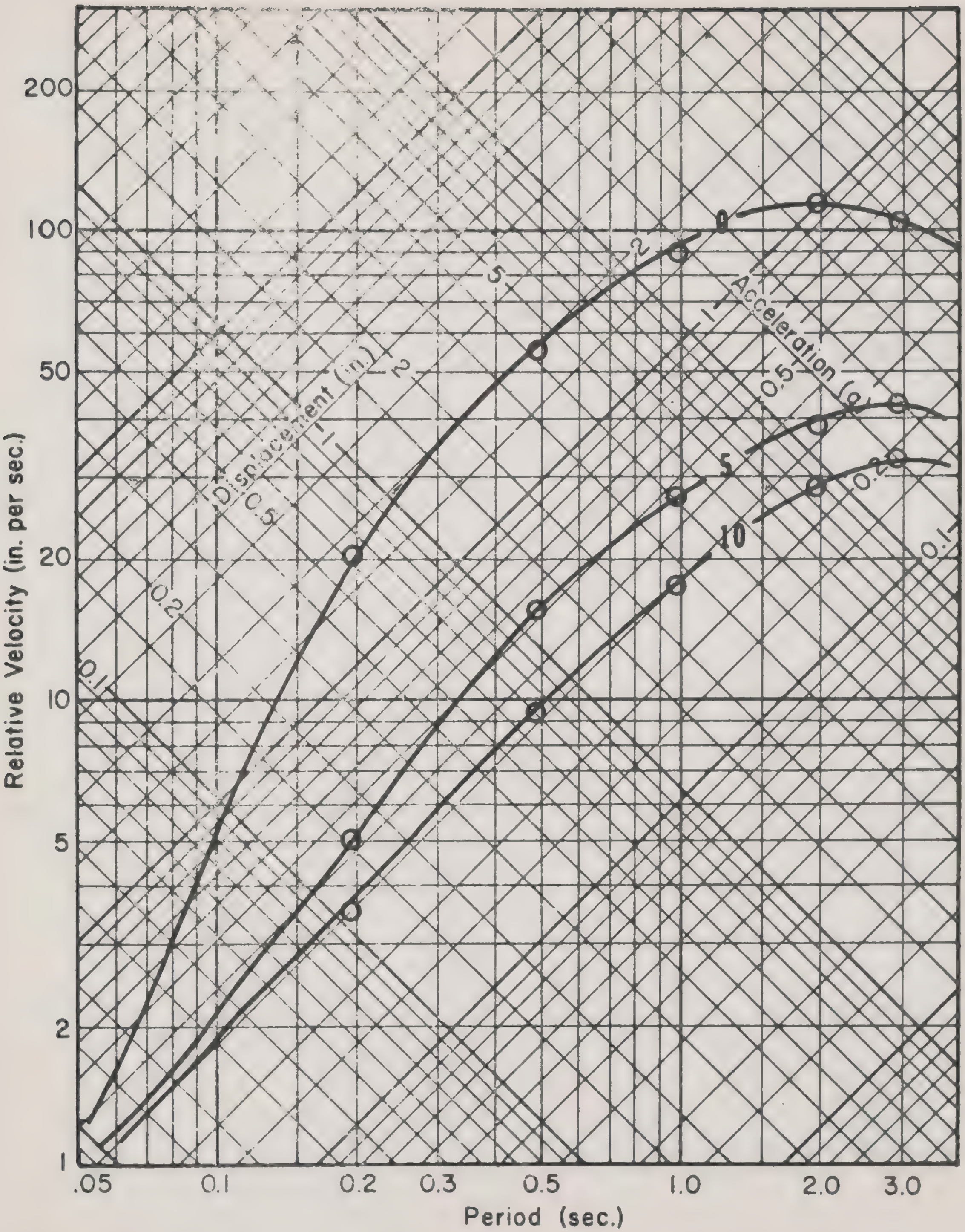


FIGURE 58. RESPONSE SPECTRUM, for 0, 5% and 10% of critical damping.

Jacalitos Trend (Zone C2)

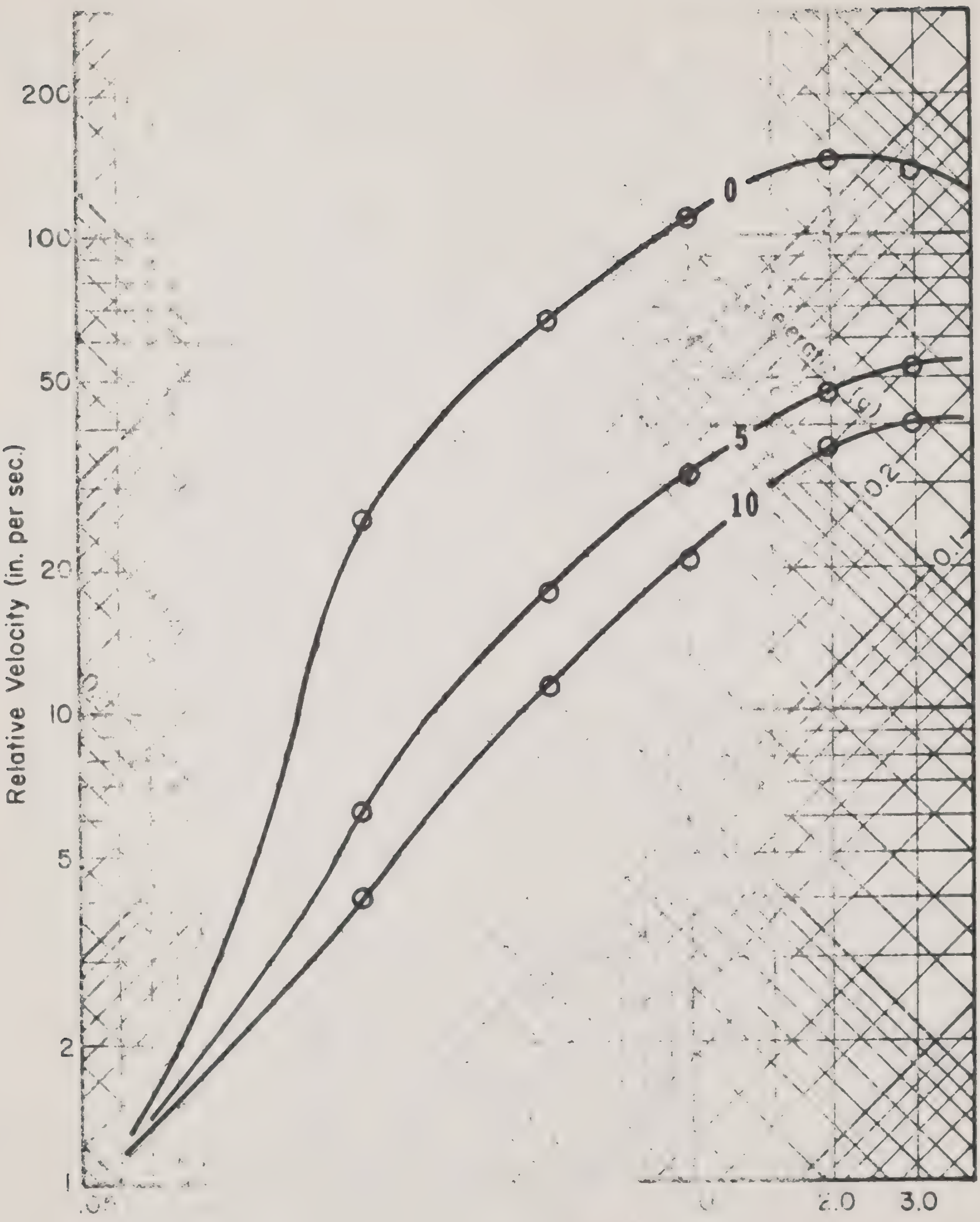


FIGURE 59. RESPONSE SPECTRUM, for 0, 5% and 10% of critical damping.

Wortham Valley (Zone C2)

GRAPHICS BY

SOURCE: ENVICOM

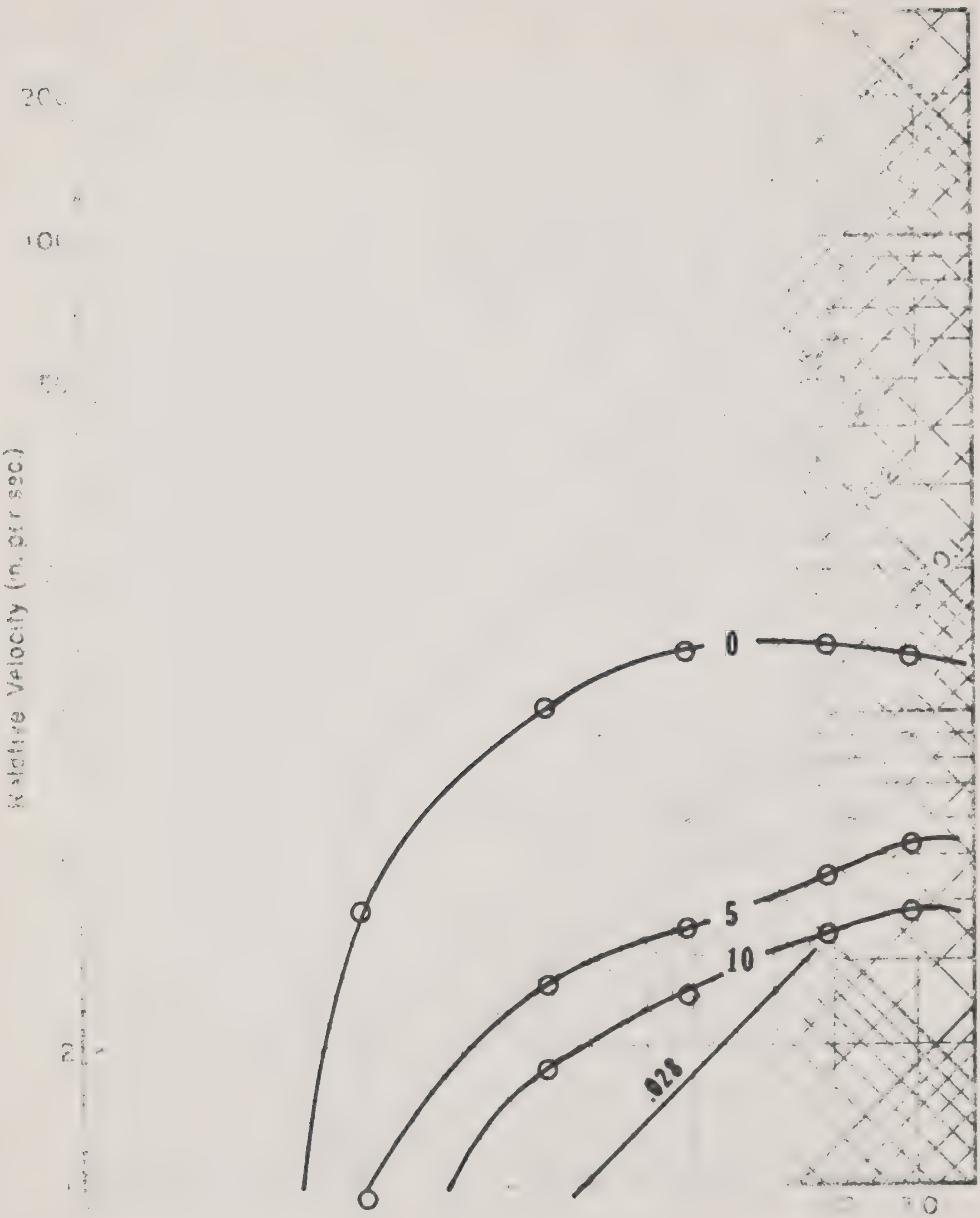


FIGURE 60. RESPONSE SPECTRUM, for 0, 5% and 10% of critical damping.

Bedrock Sites (Zone S1)

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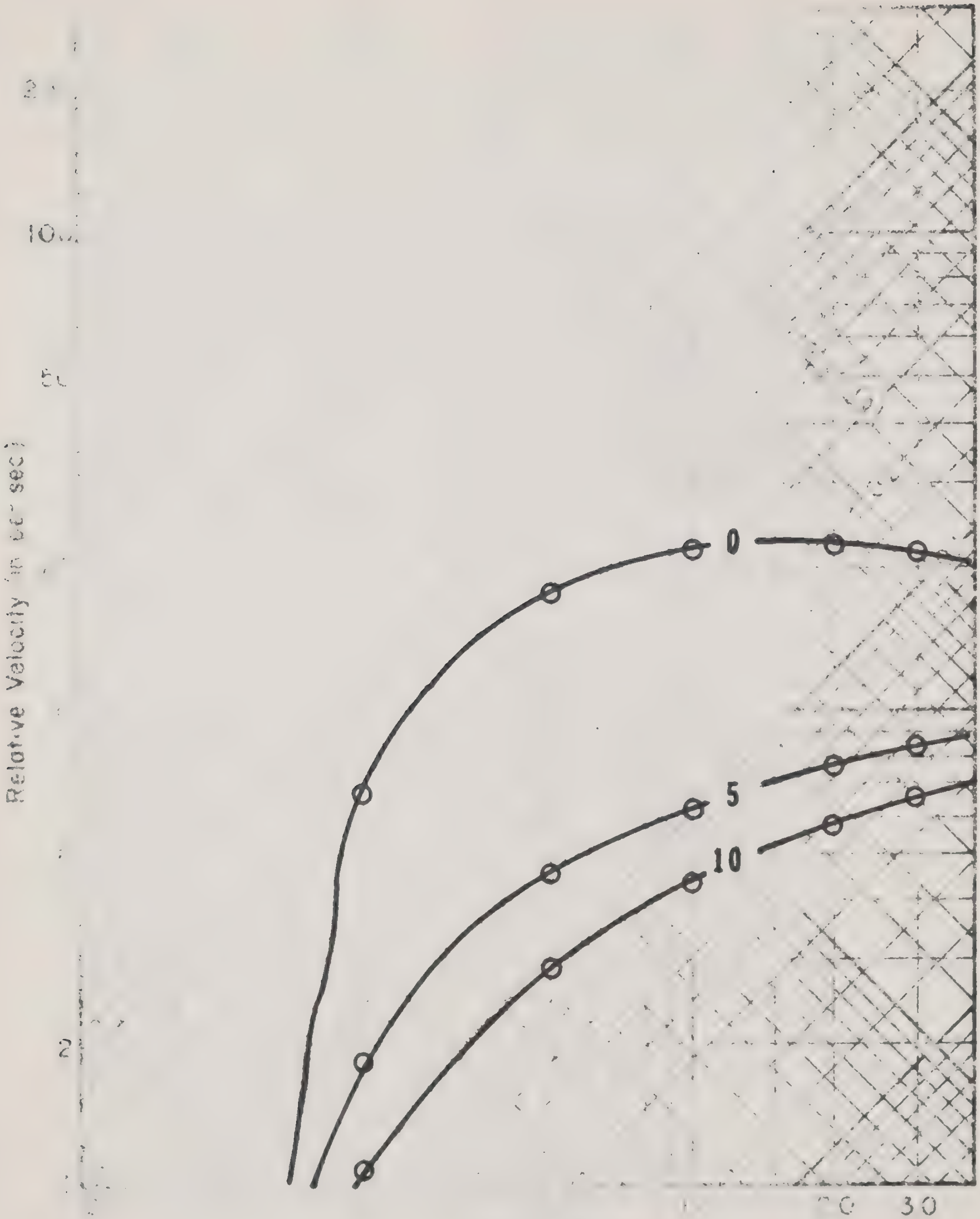


FIGURE 61. RESPONSE SPECTRUM, for 0, 5% and 10% of critical damping.

Bedrock Sites (Zone S2)

GRAPHIC SOURCE: ENVICOM

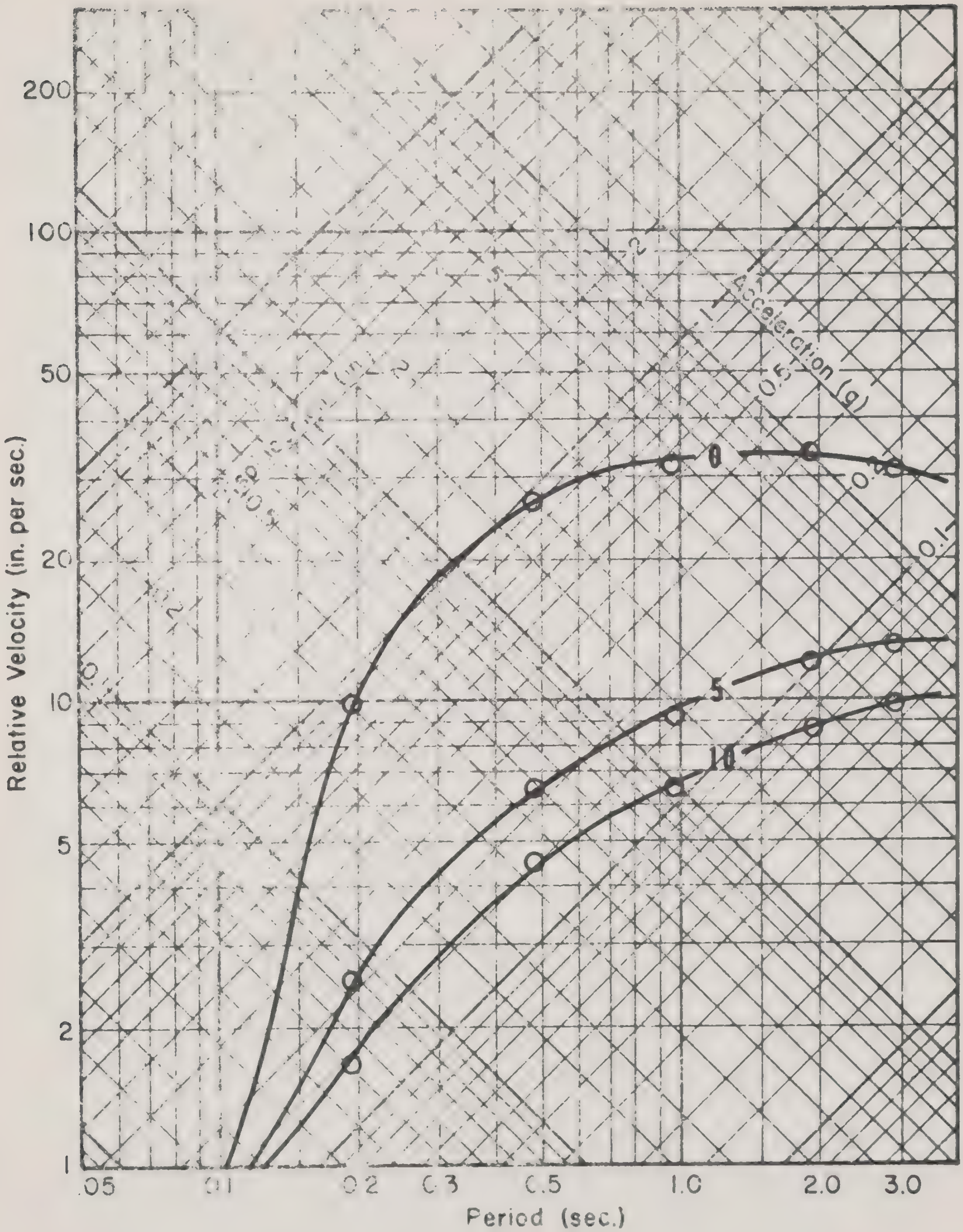


FIGURE 62. RESPONSE SPECTRUM, for 0, 5% and 10% of critical damping.

Bedrock Sites (Zone S3)

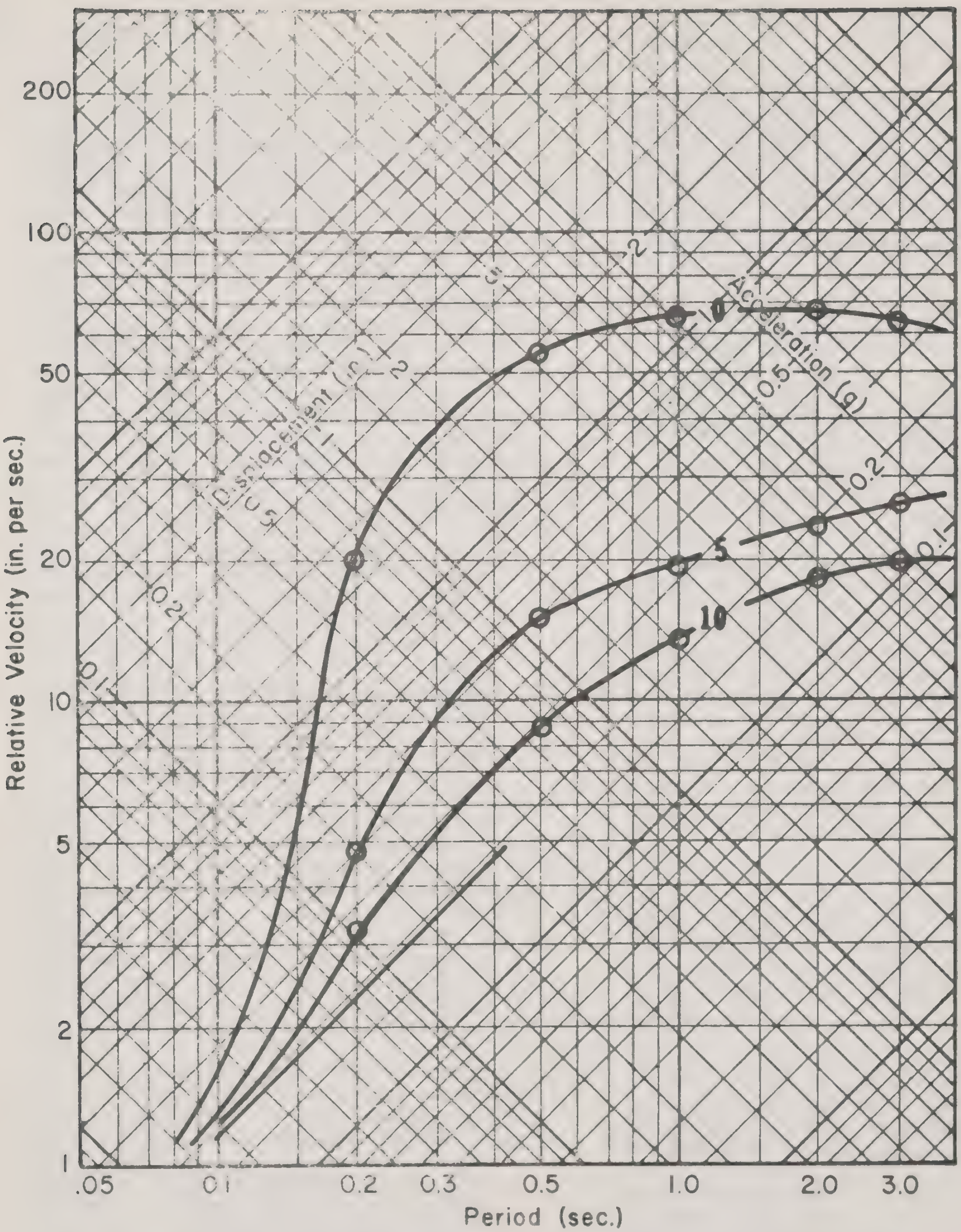


FIGURE 63. RESPONSE SPECTRUM, for 0, 5% and 10% of critical damping.

Bedrock Sites (Zone S4)

GRAPHICS BY TULARE COUNTY PLANNING DEPARTMENT SOURCE: ENVICOM

4. Sierran Zones

The zonation of the Sierra Nevada is, in some respects, more simple than the Valley or the coastal mountains, and in other ways it is more complex. The area is underlain primarily by granite rocks with lesser amounts of metamorphic and volcanic rocks. These rocks have high shear-wave velocity, very little layering, and thus a very low near-surface amplification. The problem in this area is that most of the people do not live on the hard rocks, but rather on alluvium in the valleys or deeply weathered or decomposed zones in the meadows or foothills. The characteristics of these materials vary rapidly from place to place, and the mapping of zones is not feasible within the scope and map scales of this study. Also, the grading of a particular site may alter its response characteristics considerably.

To account for these various factors of the zonation of the Sierra Nevada is presented in two steps. First, response spectra have been developed for bedrock sites for a magnitude 8.0 to 8.5 earthquake on the Owens Valley fault. These spectra are for four zones, the boundaries of which are based on distance to the causative fault. The number of zones, and therefore also the boundaries between the zones, have been chosen such that there is a significant, but not excessive, difference between the expected ground motion in each zone. The spectra for bedrock sites in these zones are shown in Figure 60 through 63, and the general characteristics of the ground motion are shown in Table 28. Since the magnitude 8 earthquake has a recurrence interval of 300 years or more, the general characteristics of the magnitude 7.0 quake (recurrence interval of 125 years) are also given.

The basic zones described above are based on the maximum probable earthquake on the Owens Valley fault. In the areas to the north and south, the maximum probable earthquakes have been determined as magnitude 7.0 and 6.0 respectively. These areas are treated as subzones of the four basic zones. Their general characteristics are shown in Table 28, and the distribution of the zones is shown on Plate I.

The above applies to bedrock sites only. The amplifying effects of surficial materials is shown in Table 29. The amplification factors should be applied to the maximum ground acceleration or the spectral velocities of the spectra for the amplified range of period depending on the thickness of the material present. The use of this table requires some professional judgement, and is intended for use by qualified engineering geologists or soils engineers.

5. Summary of Zonation and Comparison with Observed Intensity

Four zones are defined in the San Joaquin Valley. Assuming a magnitude 8.0 - 8.5 earthquake on the San Andreas fault, relatively low levels of shaking should be expected in the eastern and central parts of the Valley (Zone V1) and in the Tulare Lake area (Zone V2). Strong shaking should be expected in the western valleys near Coalinga (Zone V4), with the intermediate levels of shaking along the west side of the Valley (Zone V3). The ground motion in the nearby mountains (Zones C1 and C2) is significantly less than in Zone V4, particularly for the shorter periods, even though the former are generally closer to the fault.

The results of this zonation, which is based on a numerical analysis, is in good agreement with observed intensities during the 1906 San Francisco earthquake (Figure 19) and, to a lesser extent, with more recent earthquakes along the San Andreas fault (Figures 20 through 22). The magnitude of the latter have been relatively small, and they are not considered direct tests of the zonation because of the limited areal extent of strong shaking.

The zonation of the Sierra Nevada is more complex because of the variation due to local surficial deposits. The near-surface amplification due to these deposits is comparable to the attenuation due to distance from the causative fault. These relationships suggest an irregular pattern of expected intensity that is compatible with those observed in recent earthquakes (Figures 25 and 26).

The zonation is also generally compatible with intensities reported for the 1952 Arvin-Tehachapi earthquake (Figures 26 and 27) with the exception of the locally higher intensity along the west side of the Valley north of Coalinga. This area of higher intensity, compared to that of the east, would be expected from an earthquake originating to the west, but not from one originating on a fault located to the south. One explanation may be the :ly compacted soils in this area.

TABLE 27
SUMMARY OF DISTANCE AND AMPLIFICATION FACTORS USED IN
COMPUTING GROUND-MOTION SPECTRA IN THE COASTAL MOUNTAINS

Area and Sites Used in Computing A_2	Distance		Near-Surface Amplification and Applicable Range of Period				
			Amplification A_2		Amplification Ratio A_2/A_1		
	d_2	d_1/d_2	Short Period	Long Period	Short Period	Int. Period	Long Period
Kettleman Trend (Site 14)	23 mi	0.435	3 (0-1.6 sec)	4 (1.6-4.0 sec)	1.16 (0-1.6 sec)	--	1.2 (1.6-4.0 sec)
Joaquin Ridge (est. from Site 14)	18 mi	0.556	3 (0-1.6 sec)	2.5 (1.6-4.0 sec)	0.5 (0-4.0 sec)	--	--
Jacalitos Trend (Site 14)	12 mi	0.83	3 (0-0.9 sec)	4 (0.9-4.0 sec)	0.5 (0-0.9 sec)	0.67 (0.9-1.6 sec)	0.8 (1.6-4.0 sec)
Wortham Valley (Site 14)	5 mi	2.0	3 (0-0.9 sec)	4 (0.9-4.0 sec)	0.5 (0-0.9 sec)	0.67 (0.9-1.6 sec)	0.8 (1.6-4.0 sec)

TABLE 28
SUMMARY OF GROUND-MOTION CHARACTERISTICS
SIERRAN ZONES ON BEDROCK

	Recurrence Interval and Magnitude								
	300 years M=8.25			125 years M=7.0			135 years M=6.0		
Zone	g	T	t	g	T	t	g	T	t
S1	0.03	0.3	20	0.01	0.25	10	--	--	--
S2	0.075	0.3	25	0.04	0.25	15	--	--	--
S3	0.13	0.35	30	0.09	0.3	15	--	--	--
S4	0.19	0.35	40	0.15	0.3	20	--	--	--
S2N	--	--	--	0.04	0.25	15	--	--	--
S3N	--	--	--	0.09	0.3	15	--	--	--
S4N	--	--	--	0.15	0.3	20	--	--	--
S2S	--	--	--	--	--	--	0.02	0.2	5
S3S	--	--	--	--	--	--	0.05	0.25	10
S4S	--	--	--	--	--	--	0.10	0.25	10

g = maximum ground acceleration as a fraction of gravity

T = predominant period in seconds

t = duration of "strong" shaking in seconds

S = Sierran Zone

TABLE 29
AMPLIFICATION OF BEDROCK MOTION
BY SURFICIAL MATERIALS

Material	S-Wave Velocity	Amplification Factor	Approximate Thickness for Amplified Period of:			
			0-0.1s	0-0.2s	0-0.3s	0-0.5s
Deep Weathering	2500 - 5000'/sec.	1.5	50'	150'	--	--
Decomposed Granite	1000 - 2500'/sec.	3	30'	75'	150'	--
Alluvium	500 - 2000'/sec.	4	15'	40'	70'	140'
Compacted Fill	800 - 900'/sec.	4-5	20'	45'	75'	--

Intensity is based primarily on damage which can occur for reasons other than strong shaking. In this case, the damage may be as much related to the poor foundation conditions as it is to the level of ground shaking.

6. Relationship Between Shaking Characteristics and the Uniform Building Code

The relationships between the microzones as developed herein and the seismic design forces for the standard zones of the 1973 Uniform Building Code are shown in Table 30. This subject is developed further in the Policy Reports for the five counties, and is included here for reference purposes only.

D. SECONDARY HAZARDS

1. Settlement

Settlement may occur in poorly consolidated soils during earthquake shaking as the result of a more efficient rearrangement of the individual grains. Settlements of sufficient magnitude to cause significant structural damage are normally associated with rapidly deposited alluvial soils, or improperly founded or poorly compacted fills.

Plate I shows two major zones of "active settlement" and delineates a relatively large area, on the west side of the valley, of soils which are susceptible to settlement. The zones of "active settlement" are known to undergo extensive settling with the addition of irrigation water, but evidence for settlement due to ground shaking is not available. Since the process of more efficiently rearranging the soil grains is nearly the same whether it is initiated by the addition of water or by vibration, the potential for settlement of these soils by ground shaking must be considered.

The only urban area directly affected by these collapsible soils is the City of Coalinga. While no evidence of settling was reported in this area for the 1906 earthquake on the San Andreas fault zone, fluctuating groundwater levels may have changed the local soil characteristics. There is not sufficient subsurface data (in terms of laboratory testing) to categorically state that settlement will occur during a large earthquake, however, the data are sufficient to indicate that the potential is present.

2. Liquefaction

Liquefaction involves a sudden loss in strength of a saturated, cohesionless soil (predominantly sand) which is caused by shock or strain, such as an earthquake, and results in temporary transformation of the soil to a fluid mass. If the liquefying layer is near the surface the effects are much like that of quicksand on any structure located on it. If the layer is in the subsurface, it may provide a sliding surface for the material above it. Liquefaction typically occurs in areas where the groundwater is less than 30 feet from the surface, and where the soils are composed predominantly of poorly consolidated fine sand.

Zones within the Five-County study area where the groundwater is less than 30 feet from the surface are delineated on Plate I. Subsurface information from these zones however, indicate that the soil types are not conducive to liquefaction; they either contain too much clay (on the westerly side of the San Joaquin Valley) or are of too coarse a texture (as on the east side). Further, the maximum ground surface accelerations from the expected earthquakes are too low on the east side of the Valley to produce the shock necessary to initiate liquefaction.

Figure 64 presents graphs showing the potential for liquefaction for earthquakes with magnitudes 6.5-7.0 and 8.0-8.5. These graphs, derived from Seed and Idriss (1971) indicate that the ground acceleration must approach 0.3g before liquefaction could be anticipated in a fine, sandy soil with the relative densities typical of the San Joaquin Valley alluvial deposits (65%-75%). However, as discussed above, the available subsurface data indicate soil types mitigating against the occurrence of liquefaction.

3. Landslides

a. Types of Landslides

Landslides represent only one step in the continuous, natural erosional process. They demonstrate in a dramatic way the tendency of natural processes to seek a condition of equilibrium. The steep slopes of mountainous and hillside terrain are not in a state of equilibrium, and various erosional processes act on them to gradually reduce them to near sea level. Landsliding is an important agent in this cycle.

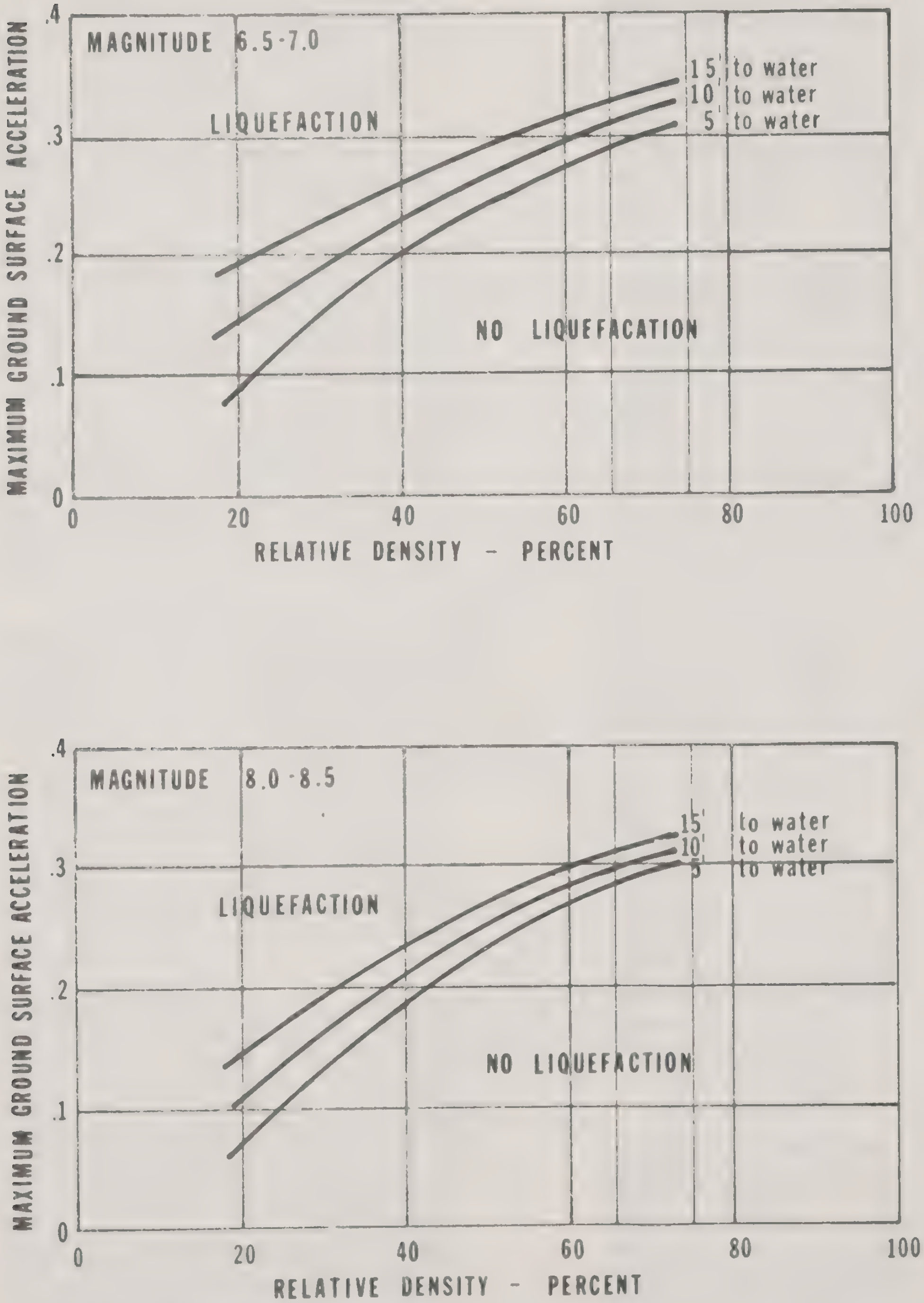
TABLE 30
UNIFORM BUILDING CODE SEISMIC ZONE AND DESIGN FORCE MULTIPLICATION FACTOR

	NORMAL FACILITIES				CRITICAL FACILITIES			
Microzone	Earthquakes (Magnitude)	Source Fault	Recurrence (years)	UBC (Zone)	Earthquakes (Magnitude)	Source Fault	Recurrence (years)	UBC (Zone)
V 1	8.0-8.5	San Andreas	100-150	II	8.0-8.5	San Andreas	100-150	II x 2
V 2	8.0-8.5	San Andreas	100-150	II	8.0-8.5	San Andreas	100-150	II x 2
V 3	8.0-8.5	San Andreas	100-150	III	8.0-8.5	San Andreas	100-150	III x 1.5
V 4	8.0-8.5	San Andreas	100-150	III	8.0-8.5	San Andreas	100-150	III x 2
C 1	8.0-8.5	San Andreas	100-150	III	8.0-8.5	San Andreas	100-150	III x 1.5
C 2	8.0-8.5	San Andreas	100-150	III	8.0-8.5	San Andreas	100-150	II X 2
S 1	7.0	Owens Valley	125	II	8.25	Owens Valley	300-10,000	II x 2
S 2	7.0	Owens Valley	125	III	8.25	Owens Valley	300-10,000	III x 1.5
S 3	7.0	Owens Valley	125	III	8.25	Owens Valley*	300-10,000	III x 1.5
S 4	7.0	Owens Valley	125	III	8.25	Owens Valley	300-10,000	III x 2
S 2 N	7.0	Owens Valley	125	II	7.0	Owens Valley	125	II x 2
S 3 N	7.0	Owens Valley	125	III	7.0	Owens Valley	125	III x 1.5
S 4 N	7.0	Owens Valley	125	III	7.0	Owens Valley	125	III x 1.5
S 2 S	6.0	Owens Valley	135	III	6.0	Owens Valley	135	III x 1.5
S 3 S	6.0	Owens Valley	135	III	6.0	Owens Valley	135	III x 1.5
S 4 S	6.0	Owens Valley	135	III	6.0	Owens Valley	135	III x 1.5

*Configuration of the S-3 Zone in extreme southern Tulare County is modified slightly for expected earthquakes from the White Wolf fault.

FIGURE 64

Liquefaction potential for earthquakes of magnitude 6.5 - 7.0 (top) and 8.0 - 8.5 (bottom)



GRAPHICS BY TULARE COUNTY PLANNING DEPARTMENT

SOURCE: ENVICOM

Several types of landslides commonly encountered include:

1. Block glides (Figure 65) - These are the largest, most impressive type of slide. The basal failure plane is controlled by planar zones of weakness such as bedding planes, joint planes, or formational contacts. Block glides typically occur in layered rocks of sedimentary or metamorphic origin where lateral support is removed by stream erosion.

2. Arcuate failures (Figure 66) - Arcuate failures are common in massive, unstructured material with relatively little resistance to shearing. These materials include thick sections of clayey soil, and poorly compacted artificial fills. The zone of failure typically describes an arc rather than a plane, and the movement of the mass is partly rotational. Small arcuate failures, called slumps, are common along steep-banked streams, where the stream has cut through an existing soil zone.

3. Mudflows (Figure 67) - Mudflows involve very rapid downslope movement of saturated soil, sub-soil, and weathered bedrock. They originate in hillside areas where the soil horizon is well developed, but the soil has poor drainage characteristics. Large mudflows may have the energy to uproot trees and to carry along boulders several feet in diameter. Because of the speed with which they move, mudflows can be quite destructive, especially along the bottoms and at the mouths of canyons.

4. Rockfalls (Figure 68) - This phenomenon, much like an avalanche of loose rock, cascades down a steep slope, disturbing more material as it passes, becoming more widespread, until it reaches the bottom of the slope. The large talus slopes common in the High Sierra country, are the debris deposited from rock falls. They are prevelant where natural slope gradients exceed 50%, and where natural weathering produces angular fragments of material with little soil cover.

b. Relationships of Earthquakes to Landslides

Lancslides should be considered a basic geologic hazard rather than one having an unusual association with earthquakes. The shaking of an earthquake only provides the triggering force to initiate downslope movement of a previously unstable earth-mass. The prime factor is the unstable condition itself. Movement could just as easily be triggered by heavy rains, or by grading on a construction project.

An extensive occurrence of seismically triggered landslides was reported to have occurred in the Five-County area in 1906 on the eastern slopes of the coast ranges along a 23-mile stretch between Panoche Creek and Cantua Creek (Lawson et al, 1908). These landslides were so extensive they were at first thought to be a secondary line of faulting. However, closer inspection indicated that they were a series of individual slides of the block glide type, with the alignment being controlled by a thick reddish-brown shale in the Tejon (?) Formation.

Rock falls were reported in the Sierra Nevada as the result of the 1872 earthquake in Owens Valley. Even though this earthquake occurred at night with observation limited to that which one could see by moonlight, there were a number of reports of spectacular rock falls. John Muir, who was in Yosemite Valley at the time, reported (from Oakshott, Greensfelder and Kahle, 1972) how he watched Eagle Rock on the south wall of the valley, fall "in thousands of the great boulders I had so long been studying." He described the sound of the falling or sliding talus as "so tremendously deep and broad and earnest, the whole earth like a living creature seemed to have at last found a voice and to be calling to her sister planets."

c. Landslide Generated Water Waves

Landsliding into lakes or reservoirs may generate large waves on the surface of the water that may do considerable damage to shore facilities, to the dam itself, or to areas downstream if the volume overtopping the dam is considerable. The potential hazard from landslide-induced water waves in the Five-County area is, therefore, related to the presence of unstable land masses on the slopes adjoining reservoirs or lakes. This possibility was checked carefully as a part of the study of aerial photographs for landslides in the area, and the results are included with the discussion of that subject.

d. Geologic Setting

The Five-County area can be divided into three distinct landslide environments: the Coast Ranges on the west, the Central Valley, and the Sierra Nevada on the east. These three divisions are geologically dissimilar and present different stability situations.

The Coast Ranges in the study area, are underlain by moderately folded sedimentary rocks of various ages ranging from Cretaceous to Quaternary. The terrain is controlled to a large extent by the geologic structure with many natural slopes parallel with the underlying bedding. Large block-glide failures occur in the Coast Ranges where stream erosion has removed support along the bedding planes.

Complexly folded and fractured metamorphic rocks of the Franciscan Group are also present in a portion of the Coast Ranges within the study area. Failures within these rocks are common, and are usually controlled by fracture patterns, cleavage planes, and sheared zones.

The Central Valley, underlain by material shed from the adjacent mountains, is basically a broad feature-less alluvial plain. The virtual absence of terrain mitigates against the occurrence of large-scale landsliding, but small slumps may be common along the banks of incised stream courses.

The Sierra Nevada comprises approximately one-third of the study area. The range is essentially a homogeneous blend of several types of granitic rocks in which many islands of older metamorphic rocks occur.

The granitic rocks are generally less-prone to landsliding than other types of rock because of their homogeneous nature and their relatively stable chemical properties. However, where the granite has been subjected to faulting, or fracturing, it too may fail along planes of weakness.

Many of the metamorphic rocks within the Sierra Nevada are complexly folded and fractured. As with similar rocks across the valley, these are prone to landslides controlled by the fracture patterns, cleavage planes, and sheared zones.

Steep slopes within the Sierra Nevada are subject to local rock-falls where an adequate soil cover in not established.

e. Landslide Risk Appraisal

1. Methodology

The appraisal of landslide risks in the Five-County area takes into account various geologic criteria, such as composition, structure, degree of folding and fracturing, and geomorphic characteristics such as terrain, direction of natural slope, etc., which combine to form situations of varying stability. These characteristics were analyzed by stereoscopically studying aerial photographs and reviewing pertinent literature. Particular attention was paid to areas adjacent to population centers, major highways through mountainous terrain, major reservoirs, and areas of encroaching urbanization.

The appraisal of slope stability is presented in terms of four levels of risk: 1) No risk, 2) Low risk, 3) Moderate risk, and 4) High risk. The final results are graphically detailed on Plate I and are discussed briefly below.

2. Risk Categories

The areas delineated as having "No risk" of landslides (category 1 on Plate I) are comprised chiefly of flatlands, valley bottoms, and areas of minimal topographic relief.

Areas assigned a "Low risk" rating (category 2 on Plate I) include hillside and mountainous terrain of competent igneous and metamorphic rocks and sedimentary rocks with favorable bedding and composition. This category encompasses much of the Sierra Nevada range, but is assigned only to local zones in the coast ranges. The "Low risk" category, as delineated on Plate I, indicates areas in a relatively stable situation in terms of landslide potential.

Those areas designated as having a "Moderate risk" of landsliding (category 3 on Plate I) include much of the Coast Ranges on the west side of the area, and several zones along the western flanks of the Sierra Nevada. The "Moderate risk" category is assigned where geologic and geomorphic characteristics have combined to produce only "semi-stable" situations. These situations include dip slopes (natural slopes parallel to bedding in sedimentary rocks), complexly folded metamorphic rocks, and zones of fractured rock.

The "High risk" areas (category 4 on Plate I) include a significant portion of the coast ranges along the west side of the area, as well as several areas within the Sierra Nevada. This designation is assigned to areas of weak rock prone to landsliding, and to existing landslides.

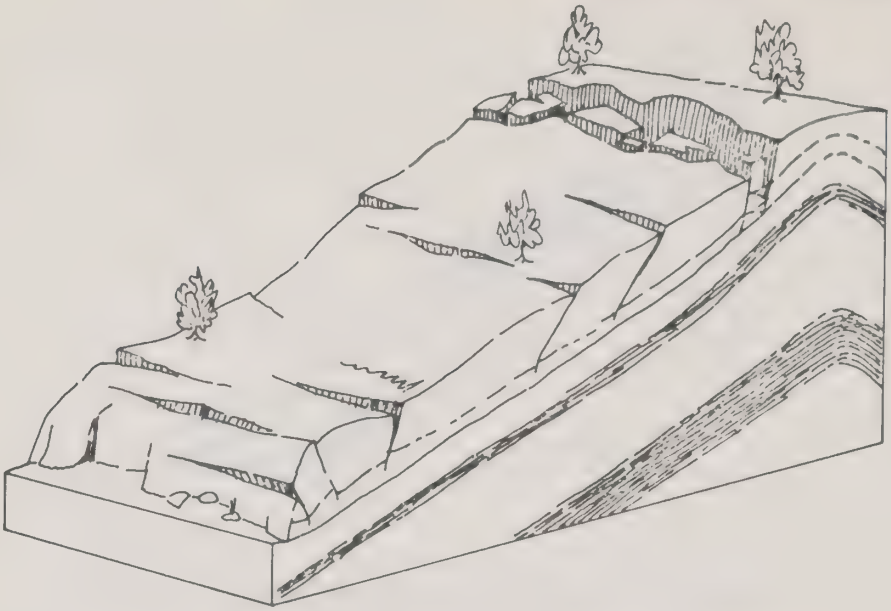


FIGURE 65 BLOCK GLIDE LANDSLIDE WHICH HAS FAILED ALONG AN UNSUPPORTED BEDDING PLANE.

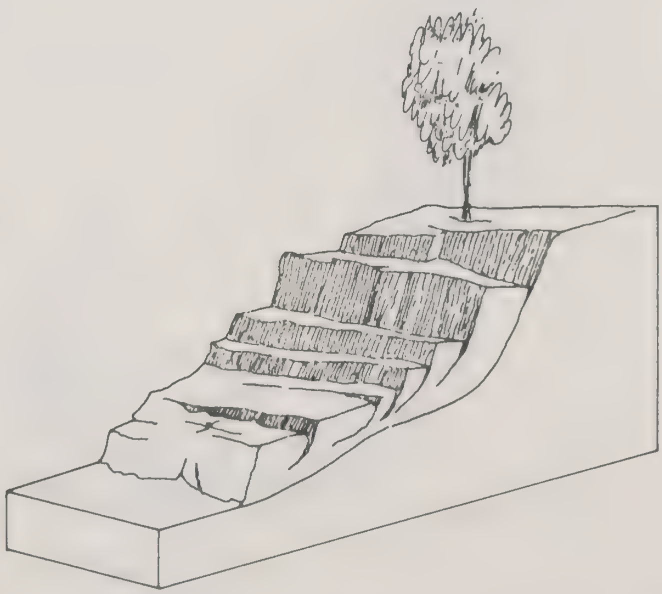


FIGURE 66 SLUMP OCCURRING IN AN UNSTRUCTURED SOIL ALONG AN ARCUATE FAILURE PATH.

FIGURE 66 FROM U. S. GEOLOGICAL SURVEY, MF 493

GRAPHICS BY TULARE COUNTY PLANNING DEPARTMENT

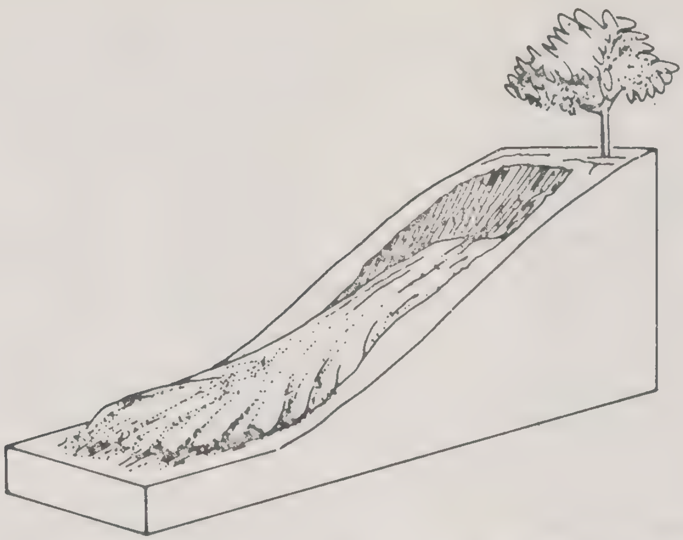


FIGURE 67 MUDFLOW OF SATURATED SOIL AND WEATHERED BEDROCK.

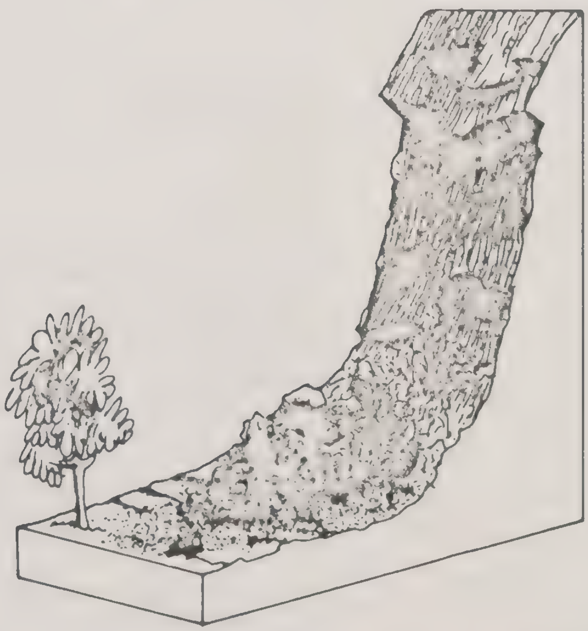


FIGURE 68 ROCKFALL INVOLVING A CASCADE OF WEATHERED BEDROCK DOWN A STEEP SLOPE.

FIGURES 67 & 68 FROM U. S. GEOLOGICAL SURVEY, MF 493

GRAPHICS BY TULARE COUNTY PLANNING DEPARTMENT

f. Summary of Landslide Hazards

No existing landslides were identified, from the aerial photographs or pertinent literature, adjacent to major highways or reservoirs within the Five-County area. However, areas appraised as having moderate and high landslide risks were found to adjoin several major highways and reservoirs as shown on Plate I.

The possibility of an underwater landslide, originating from an unstable deltaic accumulation, at a point where a stream or river enters a reservoir, cannot be completely discounted because only a small part of the accumulations are visible even from the air. However, no evidence of unusually large or apparently unstable masses of sediment were observed on the aerial photographs.

Further evaluation of specific sites within the Five-County area requires geologic and engineering data normally available only during the course of a detailed investigation of the site as well as knowledge of any modification of terrain that may be proposed for the site. This evaluation is best accomplished at the time a specific project is proposed.

E. TSUNAMIS AND SEICHES

Tsunamis, commonly called "tidal waves," are limited to oceans and areas with coastlines, and are not a hazard in the Five-County area.

Seiches are standing waves produced in a body of water by winds, atmospheric changes, the passage of earthquake waves, etc. Studies of true seismic seiches are limited, but that by McGarr and Vorhis (1968) of seiches induced by the Alaska earthquake of 1964 indicates that the largest recorded wave heights (double amplitude) did not exceed 1.2 feet. Since this is less than wave heights that would be expected from wind-induced waves, true seiches are not considered as constituting a significant hazard in the Five-County area.

A seiche-like sloshing of Tulare Lake is reported to have occurred in 1857 in response to seismic waves that accompanied the great Fort Tejon earthquake of that year (California Geology, August, 1972). The lake was very large, about 100 miles by 30 miles, and runup was reportedly as much as 3 miles. In this instance, the large area of inundation has been attributed to the low topographic relief, and had the lake been confined by levees or steeper banks the effects would have been minimal. It should also be noted that the hazard from such seismically induced inundation is not significantly different than the flood hazard in the same area, and the risk of occurrence is considerably less.

It should be noted, however, that considerable confusion exists as to the application of the term seiche. The definition included herein (see Appendix), limits a true seismic seiche to standing waves set-up by the passage of seismic waves from an earthquake. Traveling waves set-up by landsliding into or within a lake or reservoir, or those induced by the tilting of the water body, are not true seismic seiches. Dramatic examples of damage attributed at least in part to seiching at Hebgen Lake in Montana in 1959 (Christopherson, 1962) or at Kenai Lake in Alaska in 1964 (McCulloch, 1966) are more likely the results of traveling waves (or reflected traveling waves) set-up by landsliding or the tilting of the reservoir bottom. Significant tilting of major reservoirs or lakes is not expected in the Five-County area, and potential hazard from landslide-induced waves has been discussed previously under Landslides.

III CONCLUSIONS AND RECOMMENDATIONS

A. CONCLUSIONS

General

1. This report comprises the technical component of the Five County (Tulare, Fresno, Kings, Madera, and Mariposa) Seismic Safety Element. The conclusions and recommendations from this report are to be carried forward and expanded in a policy (component) report.

2. This study has been prepared in accordance with Section 65302 (f) of the Government Code which requires a Seismic Safety Element and along guidelines set forth by the California Council on Intergovernmental Relations dated September 20, 1973.

Active Faulting

1. No active faults are known within the Five-County area. Two relatively small faults may be present in south-central Tulare County that cut Pliocene and early Pleistocene rocks, but not the later Pleistocene or Recent materials. These relationships indicate that the faults have not moved in at least 100,000 years, and should not be considered a significant hazard.

2. Although geographically outside the study area, the San Andreas Fault and the Owens Valley Fault Group are considered the two principal sources of damaging earthquakes for the Five-County area.

Ground Shaking

1. The principal earthquake hazard effecting the Five-County area is ground shaking.

2. Known active faults that pose a serious hazard to the Five-County area as being the source of strong ground shaking include the San Andreas fault just west of the area, the Owens Valley fault group to the east, and possibly the White Wolf fault to the south. Analysis of available data on the seismicity, accumulating crustal strain, and rates of geologic slip yield intervals for recurrence of the maximum probable earthquake from these faults are as follows:

Fault and Segment	Magnitude of Maximum Probable Earthquake (Richter)	Recurrence Interval (years)
San Andreas fault:		
1857 Break	8.3-8.5	102-155
Transition zone	8.1-8.3	102-155
Active area	7.0	100
Owens Valley fault group:		
North area	7.0	125
Central area	8.25	300-10,000
South area	6.0	135
White Wolf fault	7.0	1,000-5,000

3. Based on the above earthquakes as sources of shaking and near-surface amplification determined from computer analysis of multi-layer models, the San Joaquin Valley area has been divided into four zones, the coastal mountains into two zones, and the Sierra Nevada into four basic zones.

4. Response spectra have been derived for the maximum probable earthquake in each zone, and the general characteristics determined for all the relevant earthquakes in each zone. These characteristics indicate that the requirements of the Uniform Building Code for Zone II will be adequate for the more populous parts of the Five-County area. Exceptions are the western San Joaquin Valley and coastal mountains, and the more easterly parts of the Sierra Nevada, particularly the alluvial valleys.

5. Comparison of the seismic zonation, developed by mathematical analysis, with the distribution of shaking intensity (isoseismal maps) for the more important historical earthquakes indicates good agreement.

6. The relationships between the seismic microzones and the seismic design forces for the standard zones of the 1973 Uniform Building Code are as follows:

Uniform Building Code Seismic Zone
and Design Force Multiplication Factor

Microzone	Normal Facilities	Critical Facilities
V 1	II	II x 2
V 2	II	II x 2
V 3	III	III x 1.5
V 4	III	III x 2
C 1	III	III x 1.5
C 2	III	III x 2
S 1	II	II x 2
S 2	III	III x 1.5
S 3	III	III x 1.5
S 4	III	III x 2

Secondary Hazards

1. Secondary seismic hazards in the Five-County area are considered to be minimal. Significant geological problems do exist, however, and are worthy of further investigation on a subregional or site-by-site basis.

2. Two major zones of "active settlement" in the west San Joaquin Valley are delineated on Plate I. These zones of active settlement are known to undergo extensive settling with the addition of irrigation water, but evidence for settlement due to ground shaking is not available.

3. The area with the greatest potential for liquefaction is the west side of the San Joaquin Valley (Plate I). Studies by the Department of Water Resources for the California Aqueduct indicate that the clay content of the poorly consolidated sediments is sufficiently high to prevent liquefaction.

4. General subsidence due to groundwater withdrawal and differential subsidence due to hydro-compaction are problems in the area of poorly consolidated sediments on the west side of the San Joaquin Valley (Plate I). This condition constitutes a geologic hazard worth of further investigation, but is not considered a seismic hazard.

5. Slope stability (landslides, mud flows, etc.) has been evaluated in terms of four levels of risk and graphically detailed on Plate I.

6. Tsunamis are not a secondary hazard in the Five-County area.

7. Seiches are not considered as constituting a significant hazard in the Five-County area.

B. RECOMMENDATIONS

Active Faulting

1. Further investigation of the two small faults in south-central Tulare County should be deferred until such time as development along or adjacent (within 0.25 mi) to them may be proposed.

Ground Shaking

1. Revision or modification of county and city building codes should be considered in those zones in which shaking is expected to exceed levels covered by existing codes.

2. Response spectra are included for use in the design of new, or the evaluation of existing major or critical facilities.

Secondary Hazards

1. The problem of hydrocompaction of the poorly consolidated sediments on the west side of the San Joaquin Valley may deserve additional study depending on land-use trends in this area. This should be considered a general geologic hazard rather than restricted to association with a major seismic event.

2. Other geologic hazards, such as landslides, potentially unstable slopes, local groundwater conditions, etc., are present particularly in the mountain and foothill terrains. Adequate evaluation of these problems normally requires detailed engineering geologic and soils engineering investigations that are economically feasible only on a project basis.

3. Chapter 70 of the Uniform Building Code should be adopted and enforced. To insure this entities involved should retain, on a full or part-time basis, a qualified engineering geologist to review the necessary reports. This procedure will be particularly important as urban development expands into the foothills and recreational development occurs in the mountains.

C. ADDITIONAL STUDIES

The review and analysis of available data, particularly that on secondary or geologic hazards, indicate that additional studies may be advisable in areas of expanding urbanization of more intensive rural use. Topics of studies that should be considered are as follows:

1. Hydrocompaction and collapsible soils. Detailed studies have been conducted along some major engineering works (Interstate 5, California Aqueduct, etc.), but the limits of the affected area is based on an interpretation of existing geologic mapping. Additional testing and analysis is advisable, particularly in the Kettlemen Plain and the expanding agricultural areas near Interstate 5.

2. Slope stability and other environmental geologic problems in the Sierran foothills. Basic information in categories such as landslide distribution, perched groundwater, sewage effluent capacity, erosion potential, etc., will be required to adequately administer public safety in areas of expanding urbanization or recreational development. This information should be developed at a scale larger (i.e. more detailed) than that of this investigation.

3. Rising perched groundwater. Increased irrigation, in response to more available water and worldwide agricultural needs, may result in perched groundwater rising to, or near, the surface in some areas along the west side of the San Joaquin Valley. Such a condition could not only result in problems related to continued agricultural use, but also the stability of structures, roads, etc., and liquefaction or settlement.

4. Lakes and reservoirs. A further analysis of lakes and reservoirs that involve human habitation along the shore or in the near-downstream should be considered. Such an analysis should consider not only seismically generated waves, but also the effects of wind-generated waves and landslides on shoreline erosion, bluff stability, etc. The scale of mapping should be larger than that used in this investigation.

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APPENDIX

GLOSSARY OF TERMS

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GLOSSARY OF TERMS

ACTIVE FAULT - One that has moved in recent geologic time and which is likely to move again in the relatively near future. Definitions for planning purposes extend on the order of 10,000 years or more back and 100 years or more forward.

ALLUVIAL - Pertaining to or composed of alluvium, or deposited by a stream or running water. (AGI, 1972)

ALLUVIUM - A general term for clay, silt, sand, gravel or similar unconsolidated detrital material deposited during comparatively recent geologic time by a stream or other body of running water as a sorted or semi-sorted sediment in the bed of the stream or on its flood plain or delta, or as a cone or fan at the base of a mountain slope. (AGI, 1972)

AMPLIFICATION - Elaboration; augmentation; addition (Webster). As used herein, near-surface amplification is the augmentation of wave amplitude resulting from the change in physical properties in near-surface layers (See Introduction).

AMPLITUDE - The extent of the swing of a vibrating body on each side of the mean position. (Webster).

BLOCK GLIDE - A translational landslide in which the slide mass remains essentially intact, moving outward and downward as a unit, most often along a pre-existing plane of weakness such as bedding, foliation, joints, faults, etc. (AGI, 1972)

COHESION - Shear strength in a sediment not related to interparticle friction. (AGI, 1972)

COLLUVIUM - (a) A general term applied to any loose, heterogenous, and incoherent mass of soil, material or rock fragments deposited chiefly by mass-wasting, usually at the base of a steep slope or cliff. (b) Alluvium deposited by unconcentrated surface runoff or sheet erosion, usually at the base of a slope (AGI, 1972)

COMPACTION - Reduction in bulk volume or thickness of, or the pore space within, a body of fine-grained sediments in response to the increasing weight of overlying material that is continually being deposited, or to the pressure resulting from earth movements within the crust. It is expressed as a decrease in porosity brought about by a tighter packing of the sediment particles. (AGI, 1972)

CONSOLIDATED MATERIAL - Soil or rocks that have become firm as a result of compaction.

DAMPING - The resistance to vibration that causes a decay of motion with time or distance, e.g. the diminishing amplitude of an oscillation. (AGI, 1972)

DIFFERENTIAL SETTLEMENT - Nonuniform settlement; the uneven lowering of different parts of an engineering structure, often resulting in damage to the structure. (AGI, 1972)

DISPLACEMENT (GEOLOGICAL) - The relative movement of the two sides of a fault, measured in any chosen direction; also, the specific amount of such movement. Displacement in an apparently lateral direction includes strike-slip and strike separation; displacement in an apparently vertical direction includes dip-slip and dip separation. (AGI, 1972)

DISPLACEMENT (ENGINEERING) - The geometrical relation between the position of a moving object at any time and its original position. (Webster)

EPICENTER - That point on the Earth's surface which is directly above the focus of an earthquake. (AGI, 1972)

FAULT - A surface or zone of rock fracture along which there has been displacement, from a few centimeters to a few kilometers in scale. (AGI, 1972)

FAULT SURFACE - In a fault, the surface along which displacement has occurred. (AGI, 1972)

FAULT SYSTEM - Two or more interconnecting fault sets. (AGI, 1972)

FAULT ZONE - A fault zone is expressed as a zone of numerous small fractures or of breccia or fault gouge. A fault zone may be as wide as hundreds of meters. (AGI, 1972)

FOCUS (SEISM) - That point within the Earth which is the center of an earthquake and the origin of its elastic waves. Syn: hypocenter; seismic focus; centrum (See Introduction) (AGI, 1972)

GROUND RESPONSE - A general term referring to the response of earth materials to the passage of earthquake vibration. It may be expressed in general terms (maximum acceleration, dominant period, etc.), or as a ground-motion spectrum.

HYPOCENTER - See focus.

INTENSITY (earthquake) - A measure of the effects of an earthquake at a particular place on humans and/or structures. The intensity at a point depends not only upon the strength of the earthquake, or the earthquake magnitude, but also upon the distance from the point to the epicenter and the local geology at the point. (AGI, 1972)

ISOSEISMAL LINE - A line connecting points on the Earth's surface at which earthquake intensity is the same. It is usually a closed curve around the epicenter. Syn: isoseismic line; isoseismal. (AGI, 1972)

LIQUEFACTION - A sudden large decrease in the shearing resistance of a cohesionless soil, caused by a collapse of the structure by shock or strain, and associated with a sudden but temporary increase of the pore fluid pressure. (AGI, 1972)

MACROSEISMIC DATA - Used herein to describe instrumentally recorded earthquakes generally in the range of Richter magnitude 3.0 or more. (This use differs from the AGI definition of "macroseismic observations.")

MAGNITUDE (earthquake) - A measure of the strength of an earthquake or the strain energy released by it, as determined by seismographic observations. As defined by Richter, it is the logarithm, to the base 10, of the amplitude in microns of the largest trace deflection that would be observed on a standard torsion seismograph (static magnification = 2800; period = 0.8 sec; damping constant = 0.8) at a distance of 100 kilometers from the epicenter. (AGI, 1972)

MICROSEISMIC DATA - Used herein to describe instrumentally recorded earthquakes generally in the range of Richter magnitude 3.0 or less. (This use is consistent with the AGI definition of microseism and microseismometer, but is more restricted than their definition of microseismic data.)

NATURAL PERIOD - The period at which maximum response of a system occurs. The inverse of resonant frequency.

NORMAL FAULT - A fault in which the hanging wall appears to have moved downward relative to the footwall. The angle of the fault is usually 45-90 degrees. There is dip-separation, but there may or may not be dip-slip. (AGI, 1972)

PREDOMINANT PERIOD - The period of the acceleration, velocity or displacement which predominates in a complex vibratory motion. In the analysis of earthquake vibrations, predominant period is normally the period of the maximum amplitude of the acceleration spectrum.

RESPONSE SPECTRUM - An array of the response characteristics of a structure or structures ordered according to period or frequency. The structures are normally single-degree-of-freedom oscillators, and the characteristics may be displacement, velocity or acceleration (see Introduction).

SEICHE - All standing waves on any body of water whose period is determined by resonant characteristics of the containing basin as controlled by its physical dimensions. (U.S. Geol. Survey Prof. Paper 544-E)

SEISMIC SEICHE - Standing waves set up on rivers, reservoirs, ponds and lakes at the time of passage of seismic waves from an earthquake. (U.S. Geol. Survey Prof. Paper 544-E)

SHEAR - A strain resulting from stresses that cause or tend to cause contiguous parts of a body to slide relatively to each other in a direction parallel to their plane of contact; specifically, the ratio of the relative displacement of these parts to the distance between them. (AGI, 1972)

SHEAR WAVE OR S-WAVE - That type of seismic body wave which is propagated by a shearing motion of material so that there is oscillation perpendicular to the direction of propagation. It does not travel through liquids. (AGI, 1972)

SLIP - On a fault, the actual relative displacement along the fault plane of two formerly adjacent points on either side of the fault. Slip is three dimensional, whereas separation is two dimensional. (AGI, 1972)

STRIKE-SLIP FAULT - A fault, the actual movement of which is parallel to the strike (trend) of the fault. (AGI, 1972)

SUBSIDENCE - A local mass movement that involves principally the gradual downward settling or sinking of the solid Earth's surface with little or no horizontal motion and that does not occur along a free surface (not the result of a landslide or failure of a slope). (AGI, 1972)

TECTONIC - Of or pertaining to the forces involved in, or the resulting structures or features of the upper part of the Earth's crust. (mod. from AGI, 1972)

TSUNAMI - A gravitational sea wave produced by any large-scale, short-duration disturbance of the ocean floor, principally by a shallow submarine earthquake, but also by submarine earth movement, subsidence, or volcanic eruption, characterized by great speed of propagation (up to 950 km/hr.), long wavelength (up to 200 km.), long period (5 min. to a few hours, generally 10 - 60 min.), and low observable amplitude on the open sea, although it may pile up to great heights (30 m. or more) and cause considerable damage on entering shallow water along an exposed coast, often thousands of kilometers from the source. (AGI, 1972)

UNCONSOLIDATED MATERIAL - A sediment that is loosely arranged or unstratified or whose particles are not cemented together, occurring either at the surface or at depth. (AGI, 1972)

WATER TABLE - The surface between the zone of saturation and the zone of aeration; that surface of a body of unconfined groundwater at which the pressure is equal to that of the atmosphere. (AGI, 1972)

PLATE I

TITLE: SEISMIC/GEOLOGIC HAZARD AND MICROZONE MAP
FRESNO, KINGS, MADERA, MARIPOSA AND TULARE COUNTIES

N

SCALE 1:250,000

5 0 5 10 15 20 MILES

5 0 5 10 15 20 25 30 KILOMETERS

PREPARED BY: ENVICOM CORPORATION, SHERMAN OAKS, CALIF.
PHYSICAL, ECOLOGICAL AND SOCIAL SCIENCE CONSULTANTS

GRAPHICS BY TULARE COUNTY PLANNING DEPARTMENT
ORIGINAL LOCATED IN ROOM 107, TULARE COUNTY COURTHOUSE, VISALIA, CALIF.

are located in the Technical Report as follows:

Zone	General Characteristics	Typical Spectra
V1	Table 26	Fig. 49
V2	26	53
V3	26	54
V4	26	55
C1	26	57
C2	28	59
S1	28	60
S2	28	61
S3	28	62
S4	28	63

V:Valley C:Coastal Mountains
S:Sierra Range

moderate fracturing, etc.) - moderate risk

Areas of weak rocks subject to failure, including existing landslides - high risk

Note: This map has been prepared utilizing available data and techniques of analysis considered appropriate to the scale of 1:250,000 (approximately 1" = 4 miles). The analysis and display of seismic/geologic hazards and the microzones at this scale has, of necessity, involved considerable generalization, and local variations that may affect conditions at an individual site may be present.

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